U.S. DEPARTMENT OF COMMERCE
National Technical Information Service

PB80-111040

Nuclear Power Plant Waste Heat Horticulture

Vermont Yankee Nuclear Power Corp, Rutland

Prepared for

Industrial Environmental Research Lab, Research Triangle Park, NC

Mar 79

United States
Environmental Protection
Agency

Industrial Environmental Research
Laboratory
Research Triangle Park NC 27711

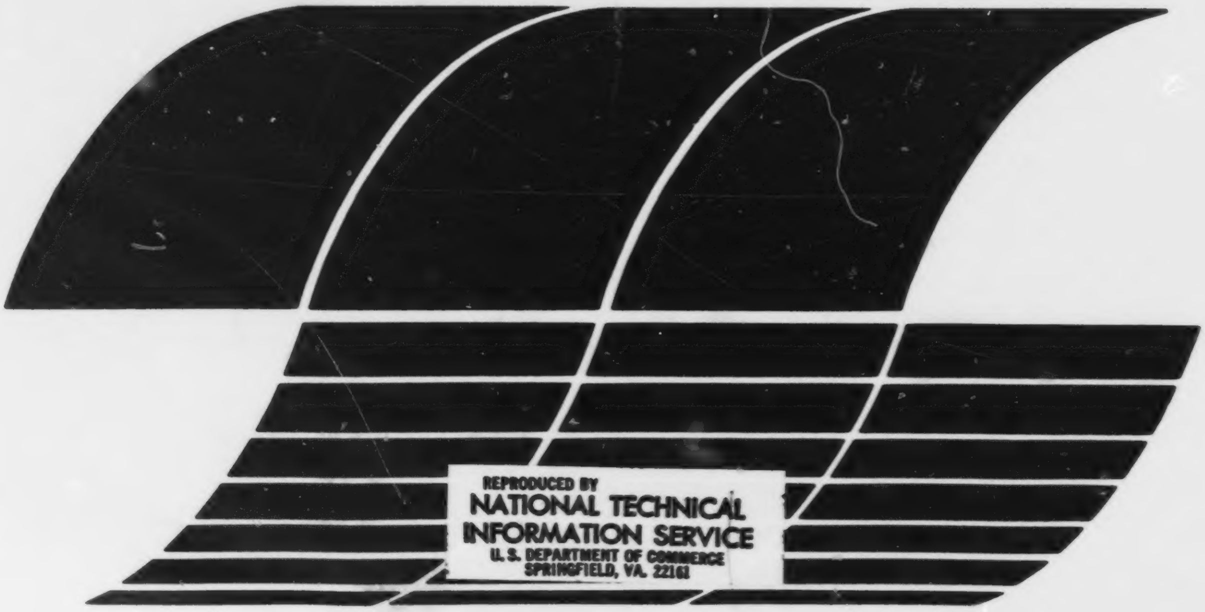
EPA-600/7-79-091
March 1979

PB80-111040

EPA

Nuclear Power Plant Waste Heat Horticulture

Interagency Energy/Environment R&D Program Report



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TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-600/7-79-091	2.	3. RECIPIENT'S ACCESSION NO. PB80-111040
4. TITLE AND SUBTITLE Nuclear Power Plant Waste Heat Horticulture		5. REPORT DATE March 1979
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Thomas Sproston (Plant Biologist Inc.), E.P. Gaines Jr., and D.J. Marx (Editors)		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Vermont Yankee Nuclear Power Corporation 77 Grove Street Rutland, Vermont 05701		10. PROGRAM ELEMENT NO. EHE624
		11. CONTRACT/GRANT NO. Grant R804715
12. SPONSORING AGENCY NAME AND ADDRESS EPA, Office of Research and Development Industrial Environmental Research Laboratory Research Triangle Park, NC 27711		13. TYPE OF REPORT AND PERIOD COVERED Final; 10/76 - 9/77
		14. SPONSORING AGENCY CODE EPA/600/13

15. SUPPLEMENTARY NOTES IERL-RTP project officer is Theodore G. Brna, MD-61, 919/541-2683. degrees

16. ABSTRACT

The report gives results of a study of the feasibility of using low grade (70 F) waste heat from the condenser cooling water of the Vermont Yankee Nuclear Plant at Vernon for commercial food enhancement. The study addressed; the possible impact of laws on the use of waste heat from a nuclear plant for food production, alternative greenhouse designs suitable for the site, and an economic and marketing model for greenhouse crops. Using surface heat exchangers for greenhouse heating appeared to permit compliance with the Delaney Amendment of the Food, Drug, and Cosmetic Act when condenser cooling water is the heating medium at a nuclear plant. The low temperature of the waste heat source suggested that supplemental greenhouse heating will be required (a biogas facility using wastes from a dairy herd near the plant was proposed as being economically attractive). A greenhouse design employing heaters using methane from the proposed biogas facility and a cropping schedule for the greenhouses was recommended. The report includes the computer program used to determine the costs of greenhouse production in the Northeast.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS		b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group	
Pollution	Greenhouses	Pollution Control	13B	02C
Nuclear Power Plants		Stationary Sources	18E	
Heat Recovery	Heating	Waste Heat	20M,13A	13H
Horticulture	Methane	Biogas	02D	07C
Condensers	Dairies	Condenser Cooling Water	13I,07A	
Cooling Water	Wastes			14G
Computer Programming			09B	

18. DISTRIBUTION STATEMENT Unlimited	19. SECURITY CLASS *(This Report)* Unclassified	21. NO. OF PAGES 140
	20. SECURITY CLASS *(This page)* Unclassified	22. PRICE A07-A01

EPA Form 2220-1 (9-73)

EPA-600/7-79-091
March 1979

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Grant No. R804715
Program Element No. EHE624

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Prepared for

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Research and Development
Washington, DC 20460

ACKNOWLEDGMENTS

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ABSTRACT

The possibility of using Vermont Yankee condenser effluent waste heat for commercial food growth enhancement was examined. It was concluded that, for the Vermont Yankee Nuclear Station, commercial success, both for horticulture and aquaculture projects, could not be assured without additional research in both areas. This is due primarily to two problems. First, the low heat quality (temperature) of the condenser discharge, being nominally 22°C ± 1°C (72° ± 2°F)* and second, to the capital-intensive support systems. The capital required for support systems includes costs of pumps, piping, controls and site work necessary to conduct heated water to growing facilities and the costs of large, efficient heat exchangers that may be necessary to avoid regulatory difficulties caused by the 1958 Delaney Amendment to the U.S. Food, Drug and Cosmetic Act.

Recommendations for further work include construction of a permanent aquaculture research laboratory and a test greenhouse complex designed by Cornell University staff, wherein several different heating configurations would be installed and tested. One greenhouse would be heated with biogas (60% methane) from an adjacent anaerobic digester thermally augmented during the winter months by Vermont Yankee condenser effluent heat.

The aquaculture laboratory would initially be used to raise fingerling Atlantic salmon (Salmo salar) to smolt size within seven months using water warmed to approximately 15°C (60°F). The growth rate by this technique is increased two to threefold over conventional hatcheries or natural conditions.

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*Whenever possible, throughout this report, data have been presented in both metric and English units. There are sections of the report, however, where metric units have not been used. This is because some data were obtained from engineering consultants who customarily use English units for professional design services. When adding metric units to the text or drawings would overly complicate reading and interpretation, they have been omitted and the reader is referred to the following conversion table:

Centimeter (cm) = Inches (in) x 0.3937
Meters (m) = Feet (ft) x 0.3048
Square meters (m^2) = Square feet (SF or ft^2) x 0.0929
Square meters (m^2) = Acres (AC) x 4047
Cubic meters (m^3) = Gallons X 0.0038
Cubic meters (m^3) = Cubic feet (ft^3) x 0.0283
Degrees Celsius (°C) = (°F - 32) x 0.56
Kilograms (kg) = Pounds (lbs) x 0.4536

PREFACE

This report is a summary of results of work sponsored by the U.S. Environmental Protection Agency (EPA) under Grant No. R804715-01-1 having the principal objective of investigating the practical possibilities of using Vermont Yankee power plant waste heat for horticultural enhancement. The report necessarily includes summary results of a corollary effort sponsored by the U.S. Energy Research and Development Agency (ERDA)* under Contract No. EY-76-C-02-2869.M001. This contract had similar objectives with regard to commercial aquaculture using Vermont Yankee waste heat. Because the two projects are interdependant by virtue of mutual support facilities (piping, pumps, service buildings, etc.), the two projects were combined into an integrated system concept. Additional aquaculture details are described in ERDA Report No. C002869-1.

The Vermont Yankee Nuclear Power Corporation believes the recommendations made herein, representing completion of the conceptual design phase of the horticulture enhancement investigation, can be satisfactorily implemented without interfering with plant electrical generating capabilities. The Corporation therefore plans to make available company-owned sites suitable for the construction of the horticulture test complex described. Furthermore, the Corporation plans to make available main condenser discharge water in volumes up to plant capacity at no cost to waste heat projects, provided such projects do not interfere with electrical generating capabilities. Finally, the Corporation plans to make available suitable personnel to function as project coordinators between plant operations and waste heat utilization programs and experiments. The Corporation looks forward to making substantial contributions to energy conservation efforts.

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*Subsequent to the commencement of this project ERDA was reorganized and incorporated into the U.S. Department of Energy.

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CHAPTER 1

SUMMARY

1.1 INTRODUCTION

Early in the evolution of current concerns over the diminishing availability of primary energy sources, the role of conservation was recognized as a major component in any practical, long-term energy program. Besides population control, discovery and recovery of additional sources of fossil fuels and the development of new "alternative" energy conversion schemes, there is the potential for improving efficiencies of the overall thermal balance of heat machines in use today so that more work is obtained from the energy consumed.

In the case of large electrical generating stations, whether nuclear or fossil, more than 50 percent of the total energy input is lost in the conversion of heat to electricity. Ideas of how to recover this energy have ranged from the design of ancillary heat engines operating in temperature regimes between exhaust gases or condenser effluent and adjacent cooling ponds and rivers to using the reject heat for melting snow and ice in nearby communities. Most of these ideas, for the present at least, can be eliminated for obvious practical reasons. Heat engines might be possible but, except for so-called combined cycle systems operated in conjunction with machines having relatively high exhaust gas temperatures, their massive dimensions require such large capital investments as to make the energy they recover uneconomical.

However, direct utilization of "waste heat" for augmented food production or growth acceleration seems worthy of further assessment. The work reported herein is the result of an initial examination into possible benefits to be obtained from using large quantities of water heated to a nominal 22°C ± 1°C (72°F ± 2°F) by the Vermont Yankee Nuclear Power Station.

1.1.1 Station Description

The Vermont Yankee Nuclear Power Station is located on the west bank of the Connecticut River immediately upstream of the Vernon hydro-electric station, in the town of Vernon, Vermont. The Vermont Yankee facility occupies about 500,000 square meters (125 acres) bounded by privately owned land to the north, south, and west and by the Connecticut River to the east.

The reactor for the Vermont Yankee Station is of the boiling water design, having a licensed thermal power of 1593 megawatts and designed net electrical rating of 514 megawatts.

In a boiling water nuclear plant, steam is passed directly from the reactor to the turbine-generator, then to the main condensers and back to the reactor vessel. The main condensers provide a dynamic heat sink for steam condensation. At Vermont Yankee this heat sink is maintained by continuously pumping water from the Connecticut River and returning the heated cooling water to the river or by pumping water cooled by the cooling towers through the condenser and back to the towers or by a combination of both these modes. The cooling towers provide the means of discharging condenser effluent heat to the atmosphere. Under nominal operating conditions, the plant condenser delta-T* is 11°C to 17°C (20°F to 30°F). At full power the plant discharges more than 1300 cubic meters (366,000 gallons) per minute of heated water, discarding approximately 3 billion BTU's per hour of "waste heat" (Figure 1.1).

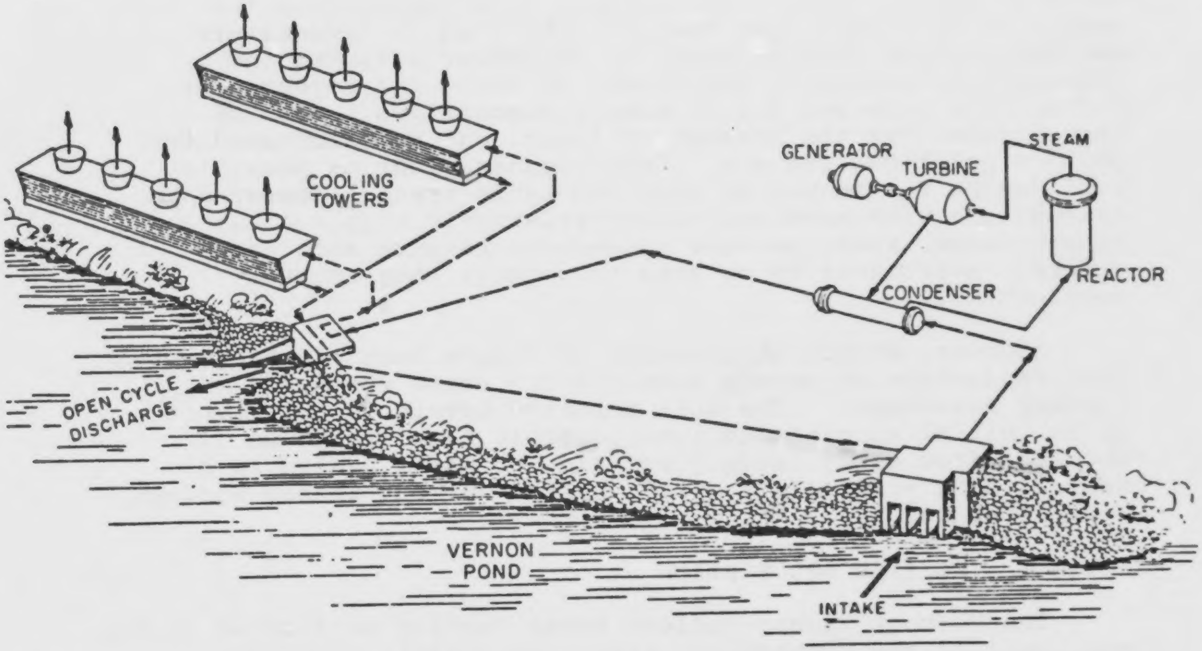

Figure 1.1 Heat Dissipation System, Vermont Yankee Nuclear Power Station

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*The temperature rise of cooling water after passage through the condenser.

1.1.2 Seasonal Temperature Profiles

Figure 1.2 illustrates typical ambient air temperatures in Vermont (11-year average, Burlington International Airport) showing that Vermont temperatures frequently average below 10°C (50°F) for more than six months of the year.

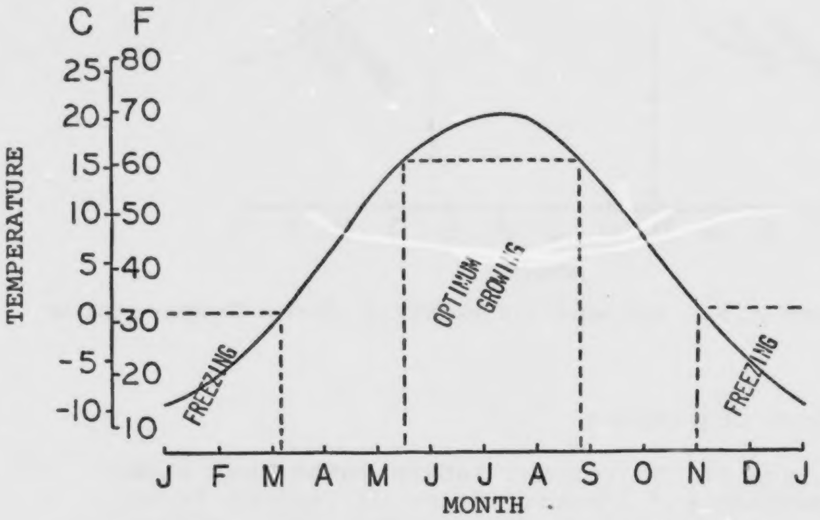

Figure 1.2 Average Vermont Temperatures

When possible, Vermont Yankee operates its cooling system to maintain an optimum pressure differential across the steam turbine. This requires a condenser discharge temperature of 22°C ± 1°C (72°F ± 2°F) which is achieved in winter by mixing ambient river water with warm water recirculated from the inner section of the discharge structure.

Thus, under normal operating conditions, large quantities of water, initially at about 22°C (72°F), are available all winter for waste heat programs. Even considering temperature losses of 5°C (10°F) through heat exchangers and conduit plumbing while in transit to waste heat projects, the potential benefits from the use of power plant discharge water are easily envisaged (the "enhanced" growing regions of Figure 1.3).

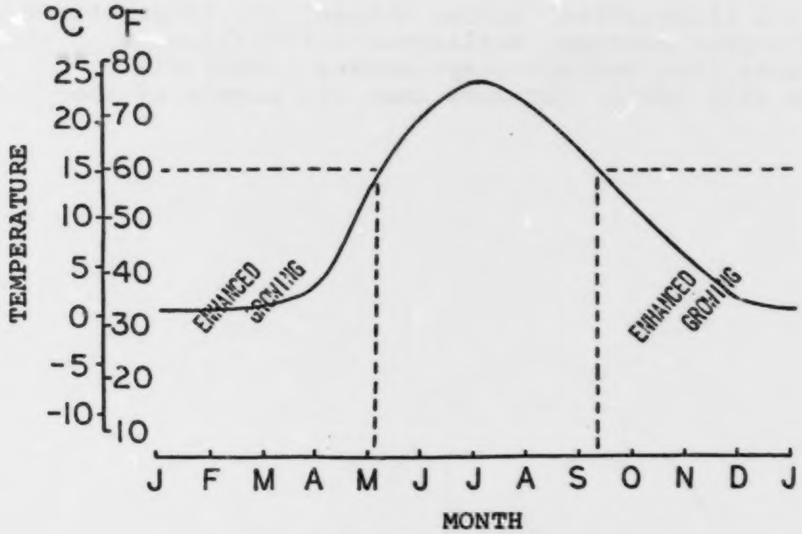

Figure 1.3 Ambient Connecticut River Temperatures

1.1.3 Project Objectives

The objectives of the Vermont Yankee waste heat study included examination and identification of Vermont Yankee operating and environmental conditions that could affect the success of commercial aquaculture and horticulture which are thermally optimized during winter months using Vermont Yankee main condenser discharge water. In pursuit of these objectives, (1) an investigation of the impact of the 1958 Delaney Amendment* to the U.S. Food, Drug and Cosmetic Act (FDCA) was undertaken; (2) plant and animal species having good potential for commercial aquaculture and horticulture were studied and selections made; and (3) a system concept integrating both horticulture and aquaculture concepts with the required support facilities was developed and analyzed. In addition, the possibility of obtaining heat at higher temperatures than available from the condenser discharge was explored with corporate engineers and consultants. It was determined, however, that this could not be done until the economics of cogeneration were better understood and the value of trading electricity generation for food products was established.

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*This law prohibits carcinogens in any amounts in food additives.

1.2 SYSTEM CONCEPT

The Vermont Yankee waste heat concept has three major components: aquaculture facilities, horticulture facilities, and mutual support systems (pumps, heat exchangers, controls, protective buildings, etc.). Figure 1.4 is a conceptual diagram of the three components. The dotted box on the left encloses the major parts of the horticulture component. (Not shown are the manure preheater, sludge holding tanks, biogas storage tanks, bi-product fertilizer storage crib, potable water source, and stand-by heating facilities.) The right hand dotted box encloses the major parts of the aquaculture component. (Not shown are the stand-by heating facilities and potable water supply.) The remaining system support component also includes roadways, conduit pipes, and an emergency electrical system as well as the pumps and heat exchangers. A fluid flow balance diagram for the integrated system is shown in Figure 1.5.

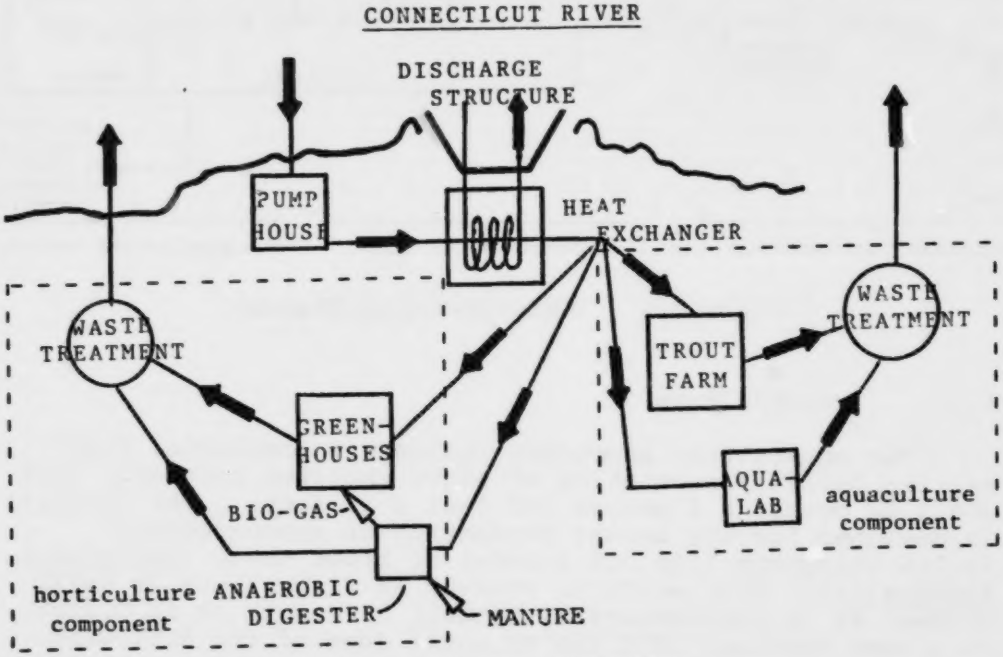

CONNECTICUT RIVER
DISCHARGE STRUCTURE
PUMP HOUSE
HEAT EXCHANGER
WASTE TREATMENT
GREEN-HOUSES
BIO-GAS
ANAEROBIC DIGESTER
MANURE
horticulture component
WASTE TREATMENT
TROUT FARM
AQUA-LAB
aquaculture component

Figure 1.4 Sketch of Vermont Yankee Waste Heat Utilization Concept

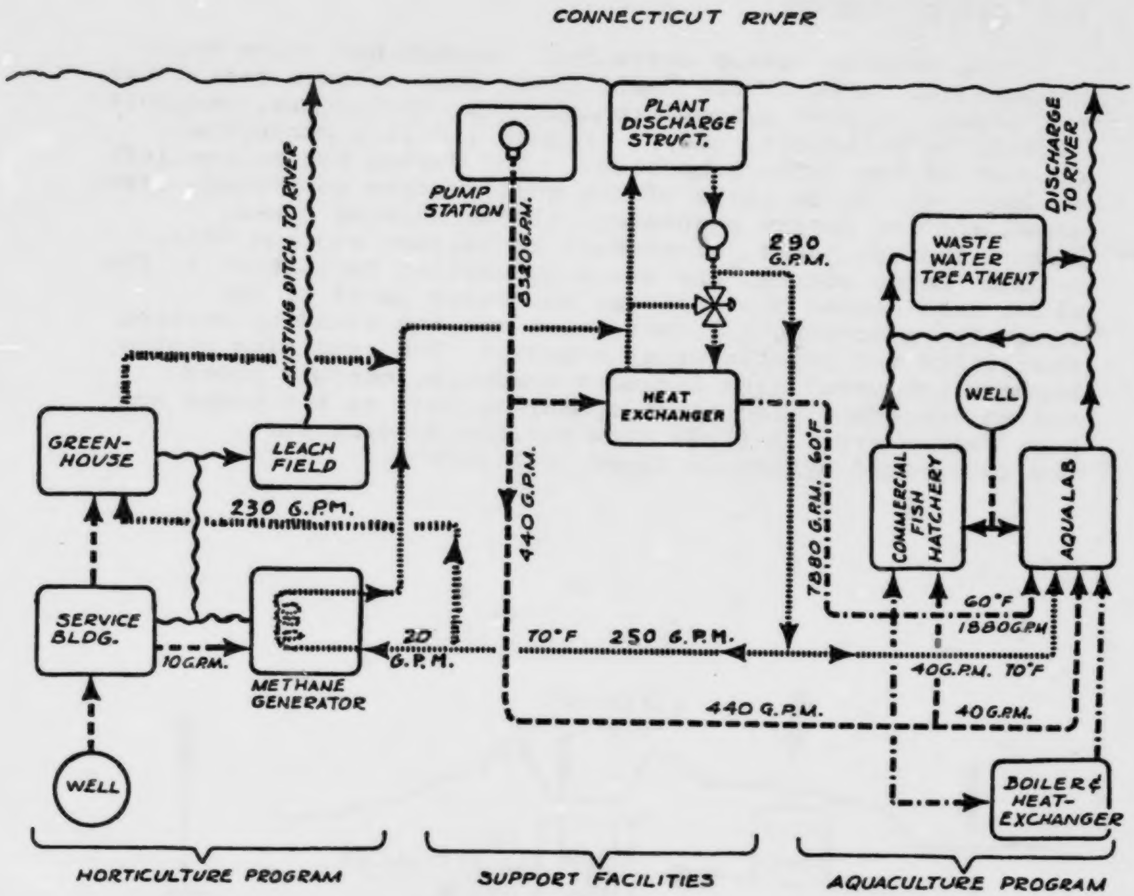

CONNECTICUT RIVER
PUMP STATION
PLANT DISCHARGE STRUCT.
EXISTING DITCH TO RIVER
DISCHARGE TO RIVER
WASTE WATER TREATMENT
8320 G.P.M.
290 G.P.M.
GREEN-HOUSE
LEACH FIELD
HEAT EXCHANGER
WELL
230 G.P.M.
440 G.P.M.
7880 G.P.M. 60°F
COMMERCIAL FISH HATCHERY
AQUALAB
SERVICE BLDG.
10 G.P.M.
METHANE GENERATOR
20 G.P.M.
70°F
250 G.P.M.
60°F
1880 G.P.M.
40 G.P.M. 70°F
440 G.P.M.
40 G.P.M.
WELL
BOILER & HEAT-EXCHANGER
HORTICULTURE PROGRAM
SUPPORT FACILITIES
AQUACULTURE PROGRAM

Figure 1.5 Fluid Flow Balance Diagram

1.2.1 Aquaculture

The aquaculture component includes a commercial fish rearing facility consisting of eight enclosed raceways, each about 24 meters x 4 meters (80 feet x 12 feet). The facility is designed for the annual production of approximately 45,000 kilograms (100,000 pounds) of brook trout (Salvelinus fontinalis). Fish would be stocked as fingerlings in early October at 10 centimeters (4 inches) in length to be reared at a near constant 13°C (55°F) until June of the following year when they would be harvested at a length of approximately 23 centimeters (9 inches).

Besides the commercial trout aquaculture facility, the aquaculture system component includes construction and long-term operation of a research facility for the study of problems of intensive, closed-system fish culture. A plan view of the aquaculture laboratory is shown in Figure 1.6. The design includes nine circular rearing tanks, each with 23 square meters (250 square feet) of surface area and eight smaller tanks providing a research area for 1,000 fish.

Water supplied to these tanks will be in continuous circular motion and maintained at a temperature of approximately 16°C(60°F). The initial goal of the facility is to produce approximately 25,000 Atlantic salmon from fingerling size to smolt between the months of September and April of the following year. This would be in support of efforts to restore Atlantic salmon to the Connecticut River and its tributaries. The long-range goal of the laboratory, however, would be to generally address problems associated with intensive closed-system aquaculture.

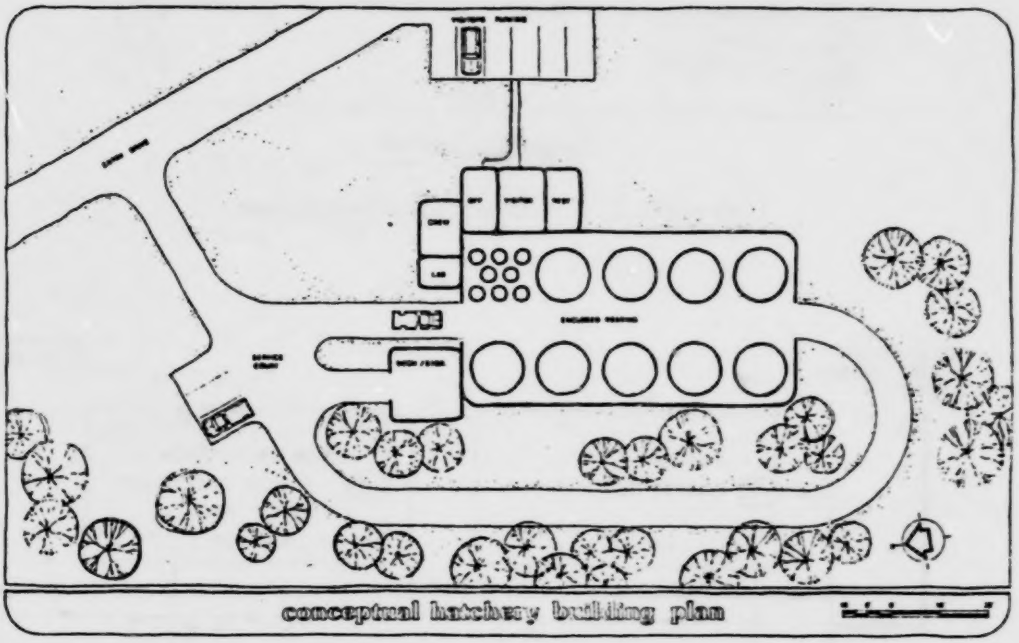


Figure 1.6 Plan View of Aqualab

1.2.2 Horticulture

The horticulture component consists of four greenhouses designed by Cornell University staff. A cross-section diagram of the greenhouse is shown in Figure 1.7. Each of the four greenhouses would be heated in a different way so that cost comparisons can be made. Figure 1.8 illustrates the four heating methods planned.

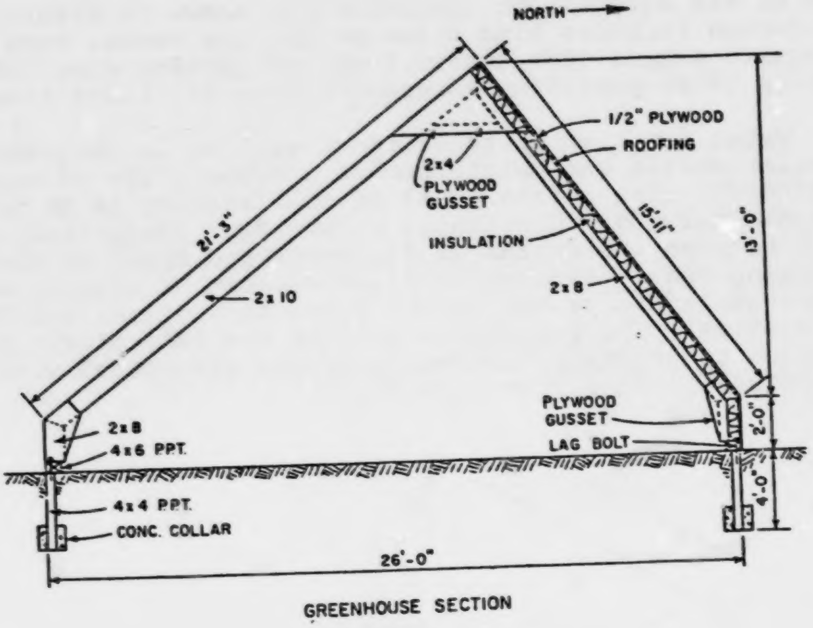
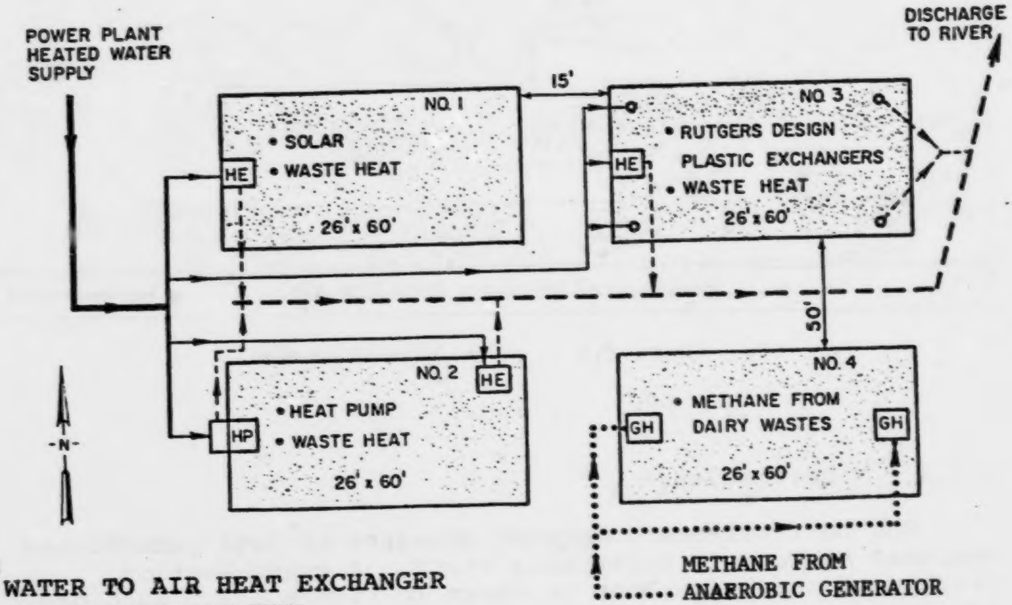

NORTH
1/2" PLYWOOD
ROOFING
2x4
PLYWOOD
GUSSET
INSULATION
21'-3"
15'-11"
13'-0"
2x10
2x8
2x8
4x6 PPT.
PLYWOOD
GUSSET
LAG BOLT
2'-0"
4'-0"
4x4 PPT.
CONC. COLLAR
26'-0"
GREENHOUSE SECTION

Figure 1.7 Cornell Greenhouse


POWER PLANT
HEATED WATER
SUPPLY
DISCHARGE
TO RIVER
15'
NO. 1
• SOLAR
• WASTE HEAT
HE
26' x 60'
NO. 3
• RUTGERS DESIGN
PLASTIC EXCHANGERS
• WASTE HEAT
HE
26' x 60'
50'
NO. 2
HE
• HEAT PUMP
• WASTE HEAT
HP
26' x 60'
NO. 4
• METHANE FROM
DAIRY WASTES
GH
GH
26' x 60'
-N-
METHANE FROM
ANAEROBIC GENERATOR

SYMBOLS:

HE	WATER TO AIR HEAT EXCHANGER
HP	WATER TO AIR HEAT PUMP
GH	UNIT GAS HEATER
———	WARM WATER SUPPLY
— — — —	DISCHARGE BACK TO RIVER
....	METHANE GAS SUPPLY

Figure 1.8 Greenhouse Heating Methods

A unique feature of the horticulture component is incorporation of an anaerobic digester, converting manure from an adjacent 200-animal dairy farm to biogas (60% methane) and concentrated fertilizer. Calculations indicate that sufficient manure is available from this source to adequately heat one of the experimental greenhouses solely by burning biogas in conventional gas heaters. The digester itself would be thermally augmented by the use of Vermont Yankee condenser effluent to preheat the manure slurry. Theoretical results indicate that this method could increase biogas production by 40% or more during winter months.

1.3 RESULTS

1.3.1 Legal Restrictions

An examination of the implications of the 1958 Delaney Amendment to the Federal Food, Drug and Cosmetic Act has been made (Appendix A). It concludes that "since the use of nuclear power plant waste heat for aquaculture and horticulture is very recent, there is little law which directly establishes standards applicable to the Vermont Yankee waste heat project. The requirements affecting the project are chiefly case-by-case permanent requirements of the Environmental Protection Agency and the Nuclear Regulatory Commission"..."The precise application of the Food, Drug and Cosmetic Act (FDCA) depends largely upon whether heat exchanger* systems are used, and if they are not, upon the probability that the circulating water will contain potentially unhealthy substances. If heat exchangers are used, as is generally contemplated, the FDCA will not apply unless food accidently becomes contaminated with poisonous or deleterious substances. If heat exchangers are not used, the Delaney Clause setting zero tolerance levels for carcinogens will still not be implicated to the extent that contamination is not to be expected, despite the fact that Vermont Yankee is a nuclear station; but a regulation may be required for certain chemicals or pipe residues contained in the cooling water. The FDCA also is implicated if particular food produced at the project becomes contaminated so as to present a health hazard."

1.3.2 Aquaculture Results

An economic model was developed for the operation of a commercial trout farm raising approximately 45,000 kilograms (100,000 pounds) of live weight fish per year. Initial results indicate that profit cannot be made in today's (1977) market from this facility due primarily to the high capital costs involved (principally the costs of heat exchangers and support facilities). In recognition that the heat exchangers as now contemplated may not be required, and to take advantage of scaling effects and other economies, the facility was enlarged by a factor of three, hypothesized to be operated without heat exchangers, and constructed as economically as possible. An analysis of the economics of such a facility with 1977 construction, operation and maintenance costs suggests a net profit, on the 1977 market, from $10,000 to $20,000 per year.

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* Editor's comment: A surface-type exchanger is intended when "heat exchanger" is used here and throughout this report.

Included in this profit is utilization of the facilities for the production of bait fish during the summer and fall months and the stocking of fish during the summer and fall months and the stocking of fingerling trout at 14 centimeters (5.5 inches) for growth to 27 centimeters (10.5 inches) during winter months. These adjustments, however, may not be biologically feasible. Therefore, it was concluded that the commercial success of a trout fish farm utilizing Vermont Yankee waste heat cannot be assured on today's (1977) market. In the future the situation may become more favorable.

However, construction and operation of the aquaculture research laboratory appears appropriate for the Vermont Yankee facility. The building and ancillary components will be constructed for a 40-year life expectancy. Capital and operation and maintenance costs for this laboratory are shown in Tables 1-1 and 1-2.

TABLE 1-1

AQUALAB CAPITAL COST SUMMARY (1977 dollars)

Sitework, Paving, and Utilities	$ 24,350
Site Mechanical	212,100
Mechanical Building (shell and electrical)	57,500
Mechanical Building (water heating system)	193,700
Rearing Building (shell)	243,000
Rearing Building (mechanical,electrical & tanks)	57,600
Furnishings, Special Equipment and Vehicles	15,700
Subtotal	$ 803,950
Mobilization @ 7%	56,280
Contingency @ 15%	129,030
Escalation (Fall 1978) 14%	138,500
Fees and Special Services	112,240
	$1,240,000

TABLE 1-2

OPERATION AND MAINTENANCE COSTS
(Aqualab - 8 months of operation)

	(1977 dollars)
Water pumping costs based on $0.015 per kwh	$18,500
Boiler heating costs based on $0.50 per gallon	
Standby	11,000
20-day shutdown	37,500
Building Utilities	1,000
Supplies (including feed)	7,000
Insurance (auto, fire, etc.)	1,000
Maintenance (vehicular, building)	10,000
Labor	
1 Manager @ $12,500/year	8,500
2 Assistants @ $10,500/year	7,000
Total	$101,500

1.3.3 Horticulture Results

An experimental greenhouse complex has been designed consisting of four Cornell greenhouses, each heated differently (Appendix C). A diagram of the experimental greenhouse complex is shown in Figure 1.9. A description of the heating systems for each greenhouse follows:

Greenhouse No. 1: Solar Greenhouse - This structure is designed to store direct solar heat in gravel beds located in the greenhouse. Heat is recovered from the gravel storage system using a commercial water to air heat exchanger. A backup heat source is provided by a 9.5-kilowatt electric resistance heater. No external solar collectors are utilized. The gravel heat storage units are also used as produce growing benches. Vermont Yankee condenser effluent is used as a "booster" heat source in the water to air heat exchanger. Tomatoes (spring and fall crops) and lettuce are planned for this greenhouse.

Greenhouse No. 2: Heat Pump - This greenhouse utilizes a water-to-air heat pump with a constant source of 18°C to 21°C (65°F to 70°F) water supplied by the power plant. The operating coefficient of performance (COP) for the water to air heat pump is approximately equal to 3 compared to 1.75 - 2.0 for air to air units now commonly used. In addition to the heat pump, one commercial water to air heat exchanger will be used, "boosted" by Vermont Yankee waste heat. The heat pump will be utilized as the backup heat source in the event of power plant down-time during the coldest operating periods. The COP in this mode, however, will be less than 2. English seedless cucumbers are planned for this house.

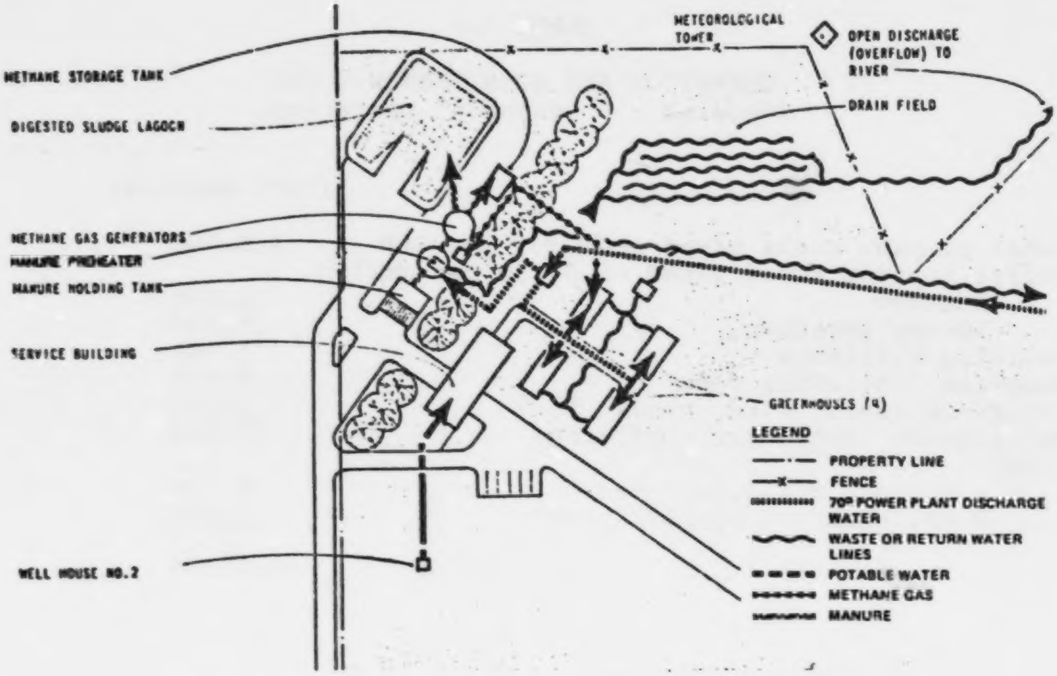
METHANE STORAGE TANK
DIGESTED SLUDGE LAGOON
METHANE GAS GENERATORS
MANURE PREHEATER
MANURE HOLDING TANK
SERVICE BUILDING
WELL HOUSE NO.2
METEOROLOGICAL TOWER
OPEN DISCHARGE (OVERFLOW) TO RIVER
DRAIN FIELD
GREENHOUSES (4)
LEGEND
PROPERTY LINE
FENCE
70° POWER PLANT DISCHARGE WATER
WASTE OR RETURN WATER LINES
POTABLE WATER
METHANE GAS
MANURE

Figure 1.9 Plan View of the Greenhouse Complex

Greenhouse No. 3: Rutgers' Design - In this design the floor is constructed of porous concrete with a gravel bed beneath it. The heat exchangers consist of perforated pipes draped with polyethylene sheets running the full length of the house in five separate rows. Water flows from the perforations in the pipe down between the plastic sheets and through the porous concrete floor into the gravel bed.

The pipes draped with plastic may be raised at night for maximum heat exchange and lowered during the day when less heat is required and more light needed for plant growth. A commercial water to air heat exchanger will assist the plastic heat exchangers. The heat exchanger combination is designed to maintain a minimum of 10°C (50°F) in the greenhouse on the coldest nights. It is planned to use this house for potted plants suitable for growth at cool temperatures (snapdragons and chrysanthemums).

Greenhouse No. 4: Methane House - This house is capable of being totally heated by methane gas produced in a nearby biogas generator (Appendix B). This generator (also known as a digester or fermenter) uses the manure from an adjacent 200-cow dairy farm. The manure is converted to a 60% methane gas mixture by an anaerobic process. The gas is piped to the greenhouse where it is burned in conventional heaters. Sufficient gas will be produced to maintain temperatures above 18°C (65°F) continually during the coldest periods. Because of the capability of maintaining high temperatures, plants such as roses can be grown in this greenhouse.

Warm water from the power plant can also be utilized as a supplemental heat source in the greenhouse and to thermally augment the anaerobic process. The digester must be maintained at 32°C-35°C (90°F-95°F) for maximum gas production. The 21°C (70°F) water from the power plant assists in maintaining the higher temperature in the digester thus increasing gas production by as much as 40%. Without the assistance of the warm water from the power plant, nearly one-half of the methane gas produced would have to be used to keep the digester at the required 32°C-35°C (90°F-95°F). Using the warm water to preheat the manure slurry in the digester during winter months results in only 10%-20% of the gas produced being required by the digester to maintain optimum operating temperatures.

Crops to be grown in the various greenhouses have been selected on the basis of the temperature fluctuations expected. The plants chosen for each greenhouse are presented in Table 1-3. Since ornamentals, especially roses, in recent years have provided New England horticulturists the highest net return on investment, it was decided to design an economic model for Greenhouse 4 (Appendix D) and examine its operation. The results are summarized in Table 1-4. Included are the effects of scaling from the original test complex of four

TABLE 1-3

ESTIMATED PRODUCTION INCOME (1977 dollars)
(Annual)

Greenhouse No. 1	
Tomatoes (fall crop)	
6lb./plant, 390 plants/house @ $.50/lb.	$ 1,170.00
Lettuce (winter)	546.00
Tomatoes (spring crop)	
14 lb./plant, 390 plants/house @ $.50/lb.	3,276.00
Total	$ 4,992.00/year
Greenhouse No. 2	
Cucumbers (English Seedless)	
5 crops (3,438 cucumbers/crop)	
@ $.40/cucumber	6,876.00
Greenhouse No. 3	
Snapdragons and 1 bench of Chrysanthemums	6,380.00
Greenhouse No. 4	
2/3 Red Roses (Forever Yours)	
1/3 Sweetheart Roses (Bridal Pink)	7,962.00
Total Gross Income	$26,210.00

TABLE 1-4

SUMMARY OF COMMERCIAL HORTICULTURE (1977 dollars)
(24 greenhouses - ornamentals, biogas heated)

Capital Investment	
First 4 greenhouses	$ 538,100
Twenty Additional Greenhouses	164,000
Additional Biogas Generators	180,000
Additional Support Facilities	105,000
Subtotal	$ 987,100
Amortized at 9.5% over 30 years	(99,600)
O & M, Greenhouses	(115,300)
O & M, Gas Generators	(14,200)
Subtotal	(229,100)
Gross Receipts, Ornamental Sales	224,600
Gross Receipts, Biogas and Fertilizer Sales	26,500
Subtotal	251,100
Approximate Net Profit	$ 22,000
*Estimated Annual Overall Rate of Return:	12%

---

*Assuming successful demonstration of test unit.

greenhouses and one biogas generator to a total of 24 houses and four biogas generators. Scaling factors, supplied by consulting engineers, resulted in an overall costs savings of 15% for the greenhouses. Scaling factors of 0.80, 0.68, and 0.65, respectively, were used for each successive biogas generator. This gave additional costs savings of about 20% for the four units. The cost of the biogas generators also includes $90,000 for gas storage facilities. The high cost of the first four greenhouses includes the cost of one biogas generator and all support systems (pumps, piping, controls, service buildings, etc.).

Operation and maintenance (O&M) costs of Table 1-4 are based upon the data of Chapter 5. Ornamental sales gross income assumes a return of $64.00 per square meter ($6.00 per square foot) of greenhouse floor space. It is believed that an efficient operation could achieve this return.

The biogas sales return assumes about 5.0×10^9 BTU of excess biogas per year available for sales at $2.50 per 10^6 BTU. The fertilizer sales assumes the processing of manure from four 200-animal dairy farms. The value of the fertilizer was based upon data cited in the ECOTOPE report referenced on page D-1, Appendix D.

1.4 CONCLUSIONS

The Vermont Yankee Nuclear Power Corporation has concluded that the construction of a permanent aquaculture research facility should be undertaken with the initial objective of contributing to the expeditious restoration of Atlantic salmon in the Connecticut River and its tributaries and with the long-term objective of contributing to fundamental understanding of problems associated with intensive closed-system fish culture. It is also concluded that waste heat-augmented horticulture can be made commercially attractive even in the Vermont winter climate. However, the parameters affecting commercial success are many and varied and their interactions sufficiently complex to justify investment in a test of the greenhouse designs and the various heating options before full-scale construction is undertaken. Regarding impact of the Delaney Amendment, it was concluded that both horticulture and aquaculture may operate commercially at the Vermont Yankee station without intermediate heat exchangers since station design and operating procedures provide sufficient barriers to radionuclides produced during normal operations. Moreover, these barriers appear to be sufficiently redundant to provide necessary consumer protection even during abnormal operating conditions. Experimental programs will establish the validity of these initial conclusions.

1.5 TEST PROGRAM IMPLEMENTATION

1.5.1 Fiscal Requirements

Capital investments of approximately $1.9 million ('77$) will be required for construction of the proposed aqualab ($1.3 million) and the four-house test horticulture complex ($600,000). Construction of the commercial fish (trout) rearing facility is excluded at this time, although land space allocation to accommodate such a facility will remain part of the Vermont Yankee long-range waste heat utilization plans.

1.5.2 Schedule

Implementation of the test program is planned in four phases, extending somewhat beyond three years and commencing as soon as preliminary design funding is available. Figures 1.10 and 1.11 are time bargraphs, showing approximate intervals and key points for events to occur, leading to operation of each facility.

The large triangles in the body of each bargraph represent specific dates when positive assurance exists that adequate funds are available to support the next phase. The numbers represent the approximate number of months duration of each phase. Horizontal arrows indicate possible time period "stretch-outs" or indefinite termination dates. The dotted vertical lines with arrows indicate when an intervening, or follow-on, step should be introduced. For example, in the first year completion of the Detailed Project Definition must include an environmental impact assessment.

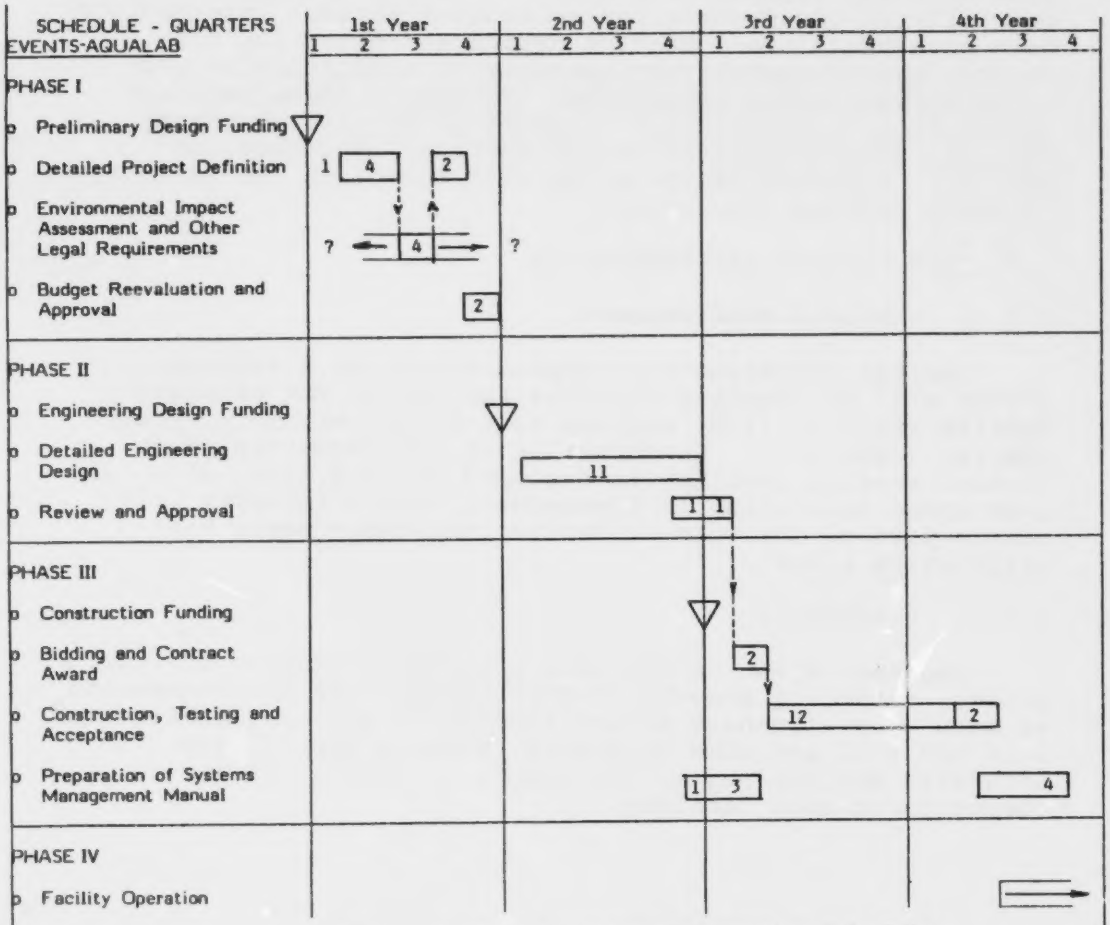

Figure 1.10 Aqualab Construction Schedule

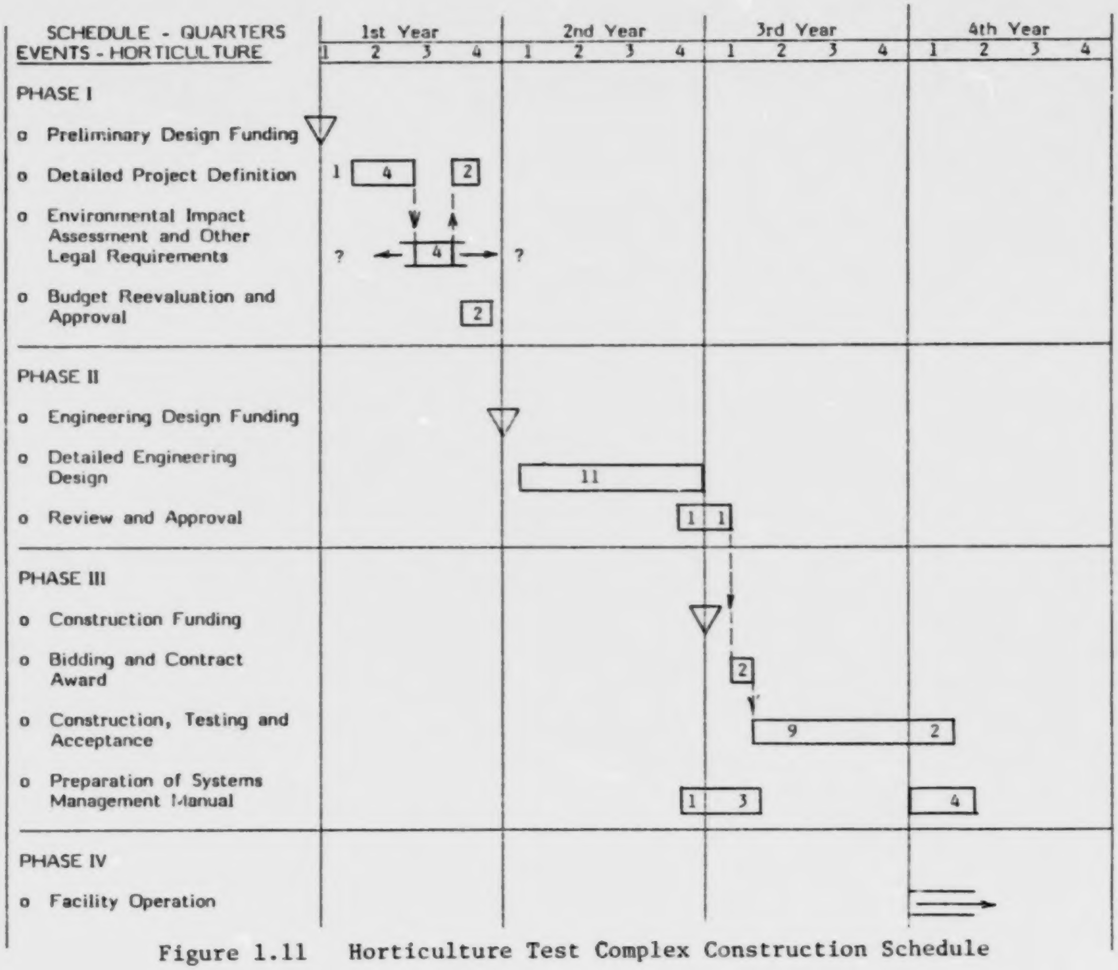

Figure 1.11 Horticulture Test Complex Construction Schedule

While it is generally expected that both projects will be undertaken concurrently, they could be undertaken separately, provided that the aqualab is constructed first. This is because the horticulture operation depends, in part, upon sharing certain support components that must be constructed for the aqualab.

CHAPTER 2

HORTICULTURE PROGRAM

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Consulting Engineers
1917 First St.
Seattle, WA 98101

2.1 GREENHOUSES (Appendix C)

2.1.1 General

Thirty years ago a significant portion of the grocery market in the Northeast was supplied by produce grown in commercial greenhouses. In recent years, however, most New England greenhouse industries have converted to specialty foods and ornamentals. This has been a direct result of the development of large, economically-refrigerated highway freight systems. Today, high fuel costs are tending to reverse the situation, and hot-house food production may again be economical in New England if low cost space heating can be provided.

2.1.2 Greenhouse Design

The basic greenhouse is about 18 x 8 meters (60 x 26 feet) and is designed with energy conservation in mind. The design incorporates a shape and appropriate construction materials that optimize the collection of solar energy while reducing the heat loss from the structure.

The greenhouse has a large, south-facing transparent surface (double-layered polyethylene) and an insulated north wall with high light-reflective interior surfaces which provide increased light levels. Basic design criteria are as follows:

Temperature

- Winter design temperature outside = -26°C (-15°F).
- Greenhouse inside temperature = 18°C (65°F) (day).
- Wastewater heat from power plant = 21°C (70°F).

Physical Criteria

- Insulation in north wall of greenhouse = R-16 (a measure of thermal resistivity).
- South wall slope elevation = 38 degrees from horizon.
- Sunshine during winter = 40% of total theoretically available.

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2.1.3 Service Building

In addition to the greenhouses, a 12 x 30-meter (40 x 100-foot) service building will provide space for research offices and the greenhouse and methane generator support facilities.

2.2 BIOGAS GENERATOR (Appendix B)

2.2.1 Process Description

Biogas generated from farm products, primarily manure, consists of 60% methane gas and 40% non-combustible gases. It would be generated by the following anaerobic digestive process. Manure from dairy cows is delivered to the methane-generating holding tank located on the plant site. It is then fed into a premix tank where 16°C (60°F) water, heated by the condenser discharge, is mixed with it to form a warm slurry. Several variables, including temperature, organic residence time and the solids retention period, affect the volatility of the bacterial anaerobic fermentation process. Since the temperature of barn-floor manure in winter may be as low as 2°C (35°F), it must be warmed for the digestive process to take place. If no external heat is applied, most of the energy of the decomposing manure would be used to maintain the natural reaction temperature of 35°C (95°F), therby reducing gas production. However, by utilizing the nuclear plant's discharge water to preheat the manure, the efficiency of the bacterial fermentation process is increased. This external heat source, plus the fermentation process, would maintain a slurry temperature of approximately 18°C (65°F). This temperature, however, is below the optimum for maximum biogas production.

From the premix tank the slurry is pumped through a heat exchanger where it is further heated by a biogas-fueled heater which raises the slurry temperature an additional 17°C (30°F). This additional heating brings the slurry to the optimum fermentation temperature of 35°C (95°F). At this temperature the slurry enters the digester where fermentation to biogas takes place. The biogas is then stored or burned in conventional gas heaters. Any excess gas would be sold or used to heat other facilities. The remaining solids are stored for later use as fertilizer.

2.2.2 Facilities

Facilities for the methane generator consist of a manure-holding premix tank capable of holding 22 cubic meters (800 cubic feet) of cow manure. This insulated, rectangular concrete tank would be below ground and would have a pumping system to provide a transfer of the slurry from the premix tank to the slurry heater. The slurry heater would be a methane-fired boiler located inside of a concrete structure. The digester, located underground so as to reduce heat loss, is sealed to prevent biogas from escaping. The volume of this tank will be approximately 140 cubic meters (5,000 cubic feet). Biogas would be pumped and condensed in a nearby tank to assure more than a one week supply of gas reserve. Service systems for the methane generator as well as administrative needs are provided.

2.3 HORTICULTURE LAYOUT

Figure 2.1 is a plan view of the four greenhouses and biogas generator test complex sited on Vermont Yankee property. The ficility would be located on the northwest corner of the property, outside the existing security fence. Although this will require transporting the discharged heated water about 1200 meters (0.75 miles), the site has the advantage of close proximity to Vermont Route 142 and a contiguous 200-animal dairy farm.

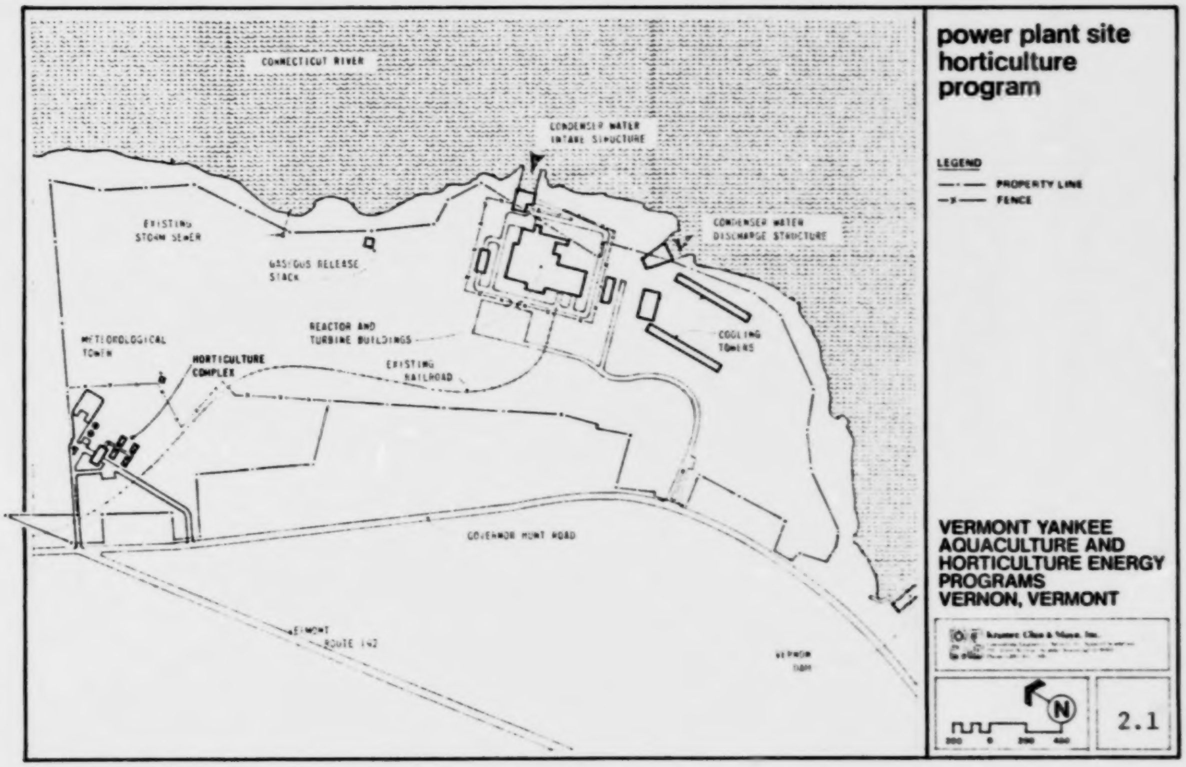
CONNECTICUT RIVER
CONDENSER WATER INTAKE STRUCTURE
CONDENSER WATER DISCHARGE STRUCTURE
EXISTING STORM SEWER
GASEOUS RELEASE STACK
REACTOR AND TURBINE BUILDINGS
COOLING TOWERS
METEOROLOGICAL TOWER
HORTICULTURE COMPLEX
EXISTING RAILROAD
GOVERNOR HUNT ROAD
VERMONT ROUTE 142
VERNON DAM
power plant site horticulture program
LEGEND
—·— PROPERTY LINE
—x— FENCE
VERMONT YANKEE AQUACULTURE AND HORTICULTURE ENERGY PROGRAMS VERNON, VERMONT
Kramer, Chin & Mayo, Inc.
N
200 0 200 400
2.1

Figure 2.1 Power Plant Siting of Horticulture Program

CHAPTER 3

SUPPORT SYSTEMS

3.1 PUMP STATION

3.1.1 General

The pump station provides 0.53 m^3/s (8,390 gpm) of ambient river water to the aquacultural and horticultural facilities. It is located approximately 91.5 meters (300 feet) upstream of the power plant intake structure in order to obtain ambient river water (Figure 3.1). This is because of the possibility of recirculation of plant discharge water back to the plant intake structure during periods of prolonged low river flow. A bar screen prevents large floating debris from entering the pump house, while a traveling motorized screen filters particles greater than 6-7 mm (1/4 inch) in size. Four pumps of varying capacities are provided to meet water pumping requirements and to provide redundancy for partial pump system failures (Figure 3.2).

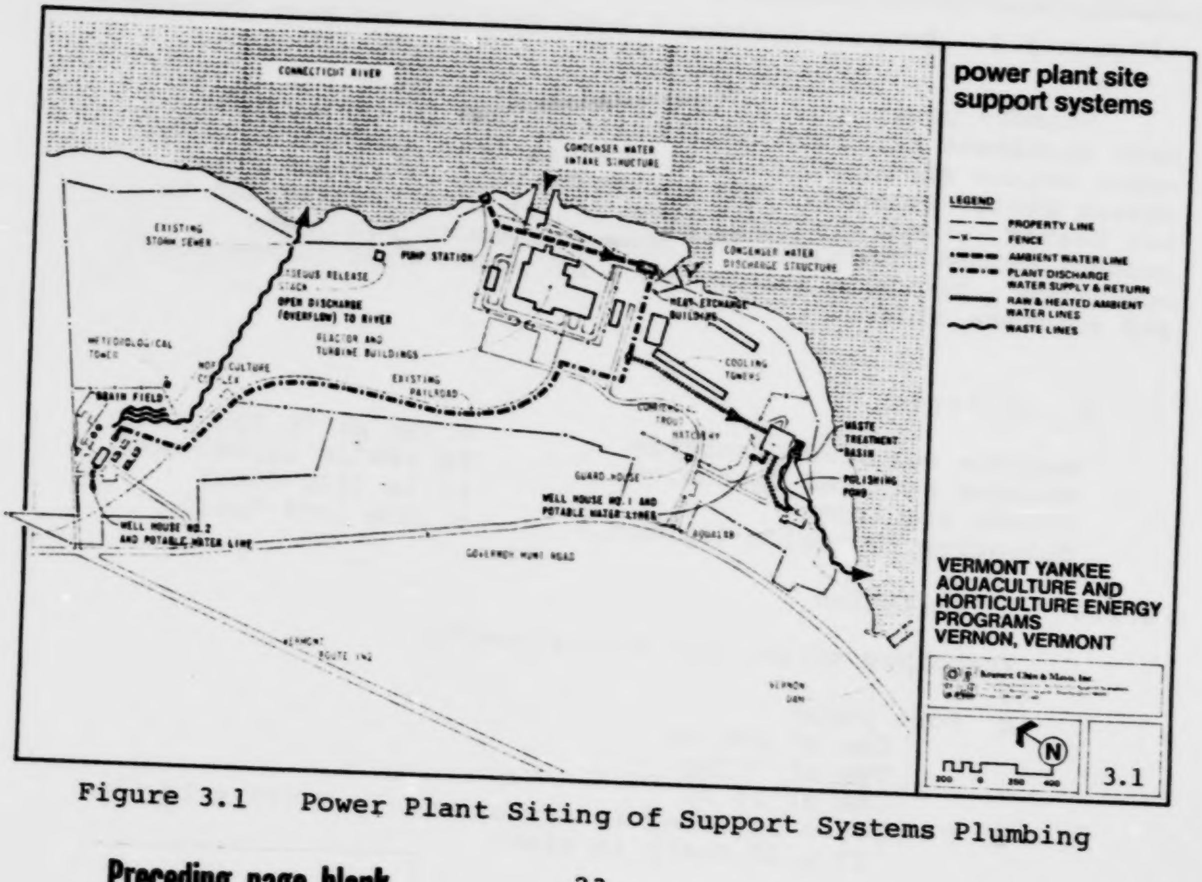
CONNECTICUT RIVER
CONDENSER WATER INTAKE STRUCTURE
EXISTING STORM SEWER
PUMP STATION
GASEOUS RELEASE STACK
OPEN DISCHARGE (OVERFLOW) TO RIVER
CONDENSER WATER DISCHARGE STRUCTURE
HEAT EXCHANGE BUILDING
METEOROLOGICAL TOWER
HORTICULTURE COMPLEX
REACTOR AND TURBINE BUILDINGS
COOLING TOWERS
DRAIN FIELD
EXISTING RAILROAD
COMMERCIAL TROUT HATCHERY
WASTE TREATMENT BASIN
GUARD HOUSE
POLISHING POND
WELL HOUSE NO. 1 AND POTABLE WATER LINES
WELL HOUSE NO. 2 AND POTABLE WATER LINE
AQUALAB
GOVERNOR HUNT ROAD
VERMONT ROUTE 142
VERNON DAM
power plant site support systems
LEGEND
PROPERTY LINE
FENCE
AMBIENT WATER LINE
PLANT DISCHARGE WATER SUPPLY & RETURN
RAW & HEATED AMBIENT WATER LINES
WASTE LINES
VERMONT YANKEE AQUACULTURE AND HORTICULTURE ENERGY PROGRAMS VERNON, VERMONT
N
200 0 200 400
3.1

Figure 3.1 Power Plant Siting of Support Systems Plumbing

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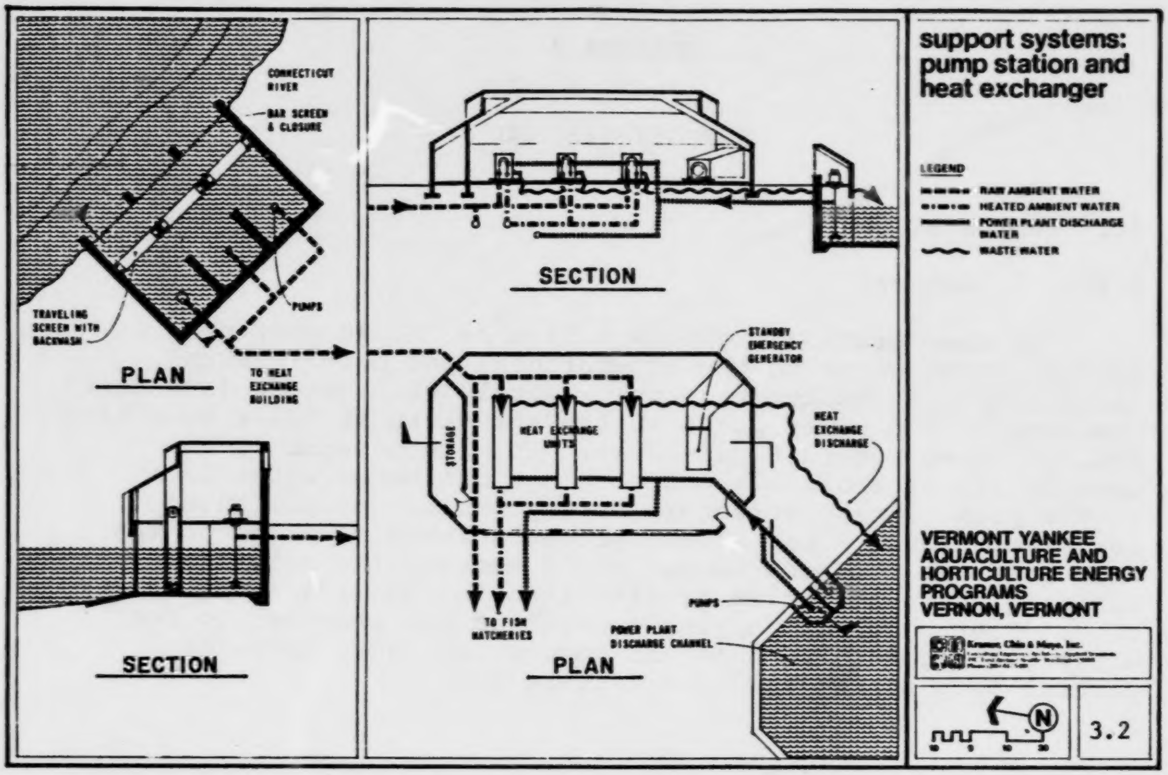
support systems: pump station and heat exchanger
LEGEND
RAW AMBIENT WATER
HEATED AMBIENT WATER
POWER PLANT DISCHARGE WATER
WASTE WATER
CONNECTICUT RIVER
BAR SCREEN & CLOSURE
TRAVELING SCREEN WITH BACKWASH
PUMPS
PLAN
TO HEAT EXCHANGE BUILDING
SECTION
STANDBY EMERGENCY GENERATOR
STORAGE
HEAT EXCHANGE UNITS
HEAT EXCHANGE DISCHARGE
PUMPS
TO FISH HATCHERIES
POWER PLANT DISCHARGE CHANNEL
SECTION
PLAN
VERMONT YANKEE AQUACULTURE AND HORTICULTURE ENERGY PROGRAMS VERNON, VERMONT
Kramer, Chin & Mayo, Inc.
N
3.2

Figure 3.2 Support Systems: Pump Station and Heat Exchanger

Standby power will be provided from a generator in the heat exchanger building. A bubbler system in the ambient water intake structure will assure ice-free operation during severe winter weather. The structure will be enclosed but not heated. Cooling and/or ventilation will be provided to support system components to assure adequate equipment operation. The pump station will be constructed of concrete and concrete blocks.

3.1.2 Criteria

Maximum required discharge	$0.53\text{m}^3/\text{s}$ (8,390 gpm)
Minimum required discharge	$56.64\text{m}^3/\text{s}$ (2,000 gpm)
Intake Elevation	67.1m (220 feet)
Discharge Elevation (approx.)	82.35m (279 feet)

3.1.3 Facilities

Traveling screen for debris removal:

- o Four pumps
  - One of 100 hp
  - Two of 50 hp
  - One of 15 hp
- o Pumphouse building is approximately 7.625 x 10.66m (25 x 35 feet) in size

3.2 HEAT EXCHANGER BUILDING

3.2.1 General

The heat exchanger building would be located adjacent to the power plant discharge structure. Water is pumped from the power plant discharge structure and heat exchanged through four plate surfaces rather than across cylindrical surfaces as in "tube type" heat exchangers. The circulated water is then returned to the discharge structure downstream of the heat exchanger pumps.

Ambient river water from the pump station is pumped through the heat exchanger, providing up to 0.50m^3/s (8,000 gpm) of 16°C (60°F) water for the rearing of fish.

The purpose of a heat exchanger between the condenser discharge water and the fish environment is to protect the fish from chemicals added to the condenser water for fouling and corrosion control. It also adds an additional barrier against any radionuclides that may be in the primary (reactor) coolant loop. Although the results of the regulatory study (Appendix A) suggest that the heat exchanger will not be necessary for commercial food production, it is planned to include it in the operation of the test facilities (aqualab and greenhouse complex). This will allow necessary comparison studies to be performed for clearly establishing the safety of food growing activities at the Vermont Yankee site and the compliance with the Delaney Amendment.

3.2.2 Criteria

Temperatures:

Minimum river water	0°C (32°F)
Minimum discharge from power plant	21°C (70°F)
Optimum rearing water	16°C (60°F)
Minimum rearing water for Aqualab (boiler backup water)	10°C (50°F)
Circulating boiler water	88°C (190°F)

Flows:

Maximum flow from power plant discharge (El. 220') to heat exchanger (El. 256')	0.63 m^3/s (10,000 gpm)
Power plant discharge to Aqualab	0.003 m^3/s (50 gpm)
Power plant discharge to methane generator and greenhouse	0.016m^3/s (250 gpm)

3.2.3 Facilities

- Four pumps at 50 hp
- Four heat exchangers at 27,984,000 BTU/hour
- One standby generator at 400 kva
- One steel, insulated building 163 sq. meters (1,750 sq. feet)

When the power plant shuts down, standby boilers will supply the aqualab with 10°C (50°F) water. The heat exchanger building will also house the standby generator to supply power to the pumps during a power outage.

Construction of the heat exchanger building will consist of a slab on grade with masonry walls. The roof will be of insulated metal construction. This construction technique will be compatible with the existing structures and the Vermont climate. The building will not be heated but ventilation will be provided for the proper functioning of the equipment. Storage will be provided for maintenance equipment. A monitoring and electrical panel vault will also be housed within the heat exchanger building. Overhead doors will permit the removal and replacement of heat exchange elements within the building.

3.3 WASTEWATER TREATMENT FACILITIES

The aquaculture program will produce the following types of wastewater:

1) Domestic
2) Hatchery/lab overflow
3) Hatchery/lab cleaning

Domestic wastewater will be treated through the use of a septic tank and an underground drain field. Hatchery/lab overflow wastewater will not require pretreatment prior to discharge into a polishing pond*.

Hatchery/lab cleaning wastewater, however, will be pretreated prior to its introduction into a polishing pond. The combined overflow and pretreated cleaning wastewater will be of such quality that the total effluent discharged from the polishing pond will meet all applicable state and federal guidelines and regulations.

Overflow from the polishing pond will flow into the Connecticut River via a natural drainage ditch.

Plant discharge water, supplied to the aqualab for experimental use, will be returned to its source.

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*A temporary water retention basin commonly used for final (5%) clean-up of wastewater.

The horticulture program will produce the following types of wastewater:

1) Domestic
2) Greenhouse drainage
3) Digested sludge from the methane generator

Domestic wastewater will be treated by a septic tank and drain field system. Drainage wastewater will be presettled and introduced into a leaching field. An underdrain from the drain field will be diverted to an existing ditch flowing into the Connecticut River.

Stabilized sludge from the digester sludge lagoon will be disposed of as fertilizer for direct land application. Appropriate bacteriological and chemical analysis will be performed as necessary on sludge prior to direct land application.

3.4 ON-SITE AND OFF-SITE WORK

- o Grading:
  Little grading will be required since the site is level and the facilities have been located to fit the existing topography. Funds have been included in the cost estimate for erosion control and for some landscaping.

- o Roadways:
  Roads will be constructed to the aquaculture and horticulture facilities. Access to the pump station and the heat exchanger building will be by existing roads.

  Roadway Criteria

  Materials: 0.05-meter (2-inch) thickness of asphalt concrete paving over 0.23 meters (9 inches) of gravel base.

  Widths:

One-lane traffic	3.6 meters (12 feet)
Two-lane traffic	6.7 meters (22 feet)
Parking areas	13.1 meters (43 feet)

  Drainage: Cross-drainage will be carried by culverts No storm sewers are anticipated.

  Lighting: Parking areas and entries will have security lighting.

- o Utilities:
  Electric power and telephone lines are available at the site. Major power services will be at the pump station, heat-exchanger building, and horticulture facility. A well will be constructed at both the aquacultural facility and the horticultural facility.

3.5 PLANT DISCHARGE WATER

Plant discharge water, taken from the power plant discharge structure, is used as the heating medium for the ambient water entering the heat exchangers, for heating the manure required for the methane generator supplying supplemental energy to the greenhouses, and for experimental purposes at the aqualab. All removed plant discharge water is returned to the power plant for discharge. All supply piping will be insulated. The minimum temperature of the plant discharge water is 21°C (70°F).

3.6 HEATED AMBIENT WATER

Heated ambient water is river water that is heated by heat exchangers to 16°C (60°F). This water is used to raise fish in both the aqualab and fish hatchery. All heated ambient water piping will be insulated. When the power plant is shut down, sufficient water to operate the aqualab will be heated to 10°C (50°F) by oil-fired boilers.

3.7 RAW AMBIENT WATER

Raw ambient water is river water that is not heated. The only treatment of the raw ambient water is debris screening at the pump house. Raw ambient water is used at both the aqualab and the fish hatchery for rearing fish and service water.

3.8 WELLS

Two wells will be constructed, one near the aquacultural facility and one near the horticultural facility. The aquaculture well will be used only for potable water and toilet facilities. The horticulture well will be used for both potable water and service water for the greenhouses.

CHAPTER 4

COST ESTIMATES

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Engineering Consultants
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Seattle, WA 98101

4.1 CAPITAL COSTS INCLUDING CONSTRUCTION

4.1.1 Purpose

The purpose of this preliminary cost estimate at the conceptual stage is to provide initial cost information for the construction program budget. It includes costs for all items needed to complete all growing and test programs*. The costs are based on 1977 dollars (or equivalent statement to establish value of "dollars").

4.1.2 Cost Factors and Assumptions

Forty-year building life is assumed for mechanical equipment systems, while 25-year design life is assumed for building enclosures.

- Overtime:
  No allowance has been made for overtime work.
- Weather Conditions:
  Normal conditions are assumed. No consideration has been given to unusual weather extremes.
- Labor:
  Prices reflect the work being performed by one licensed and bonded general contractor.
- Overhead and Profit:
  The unit prices used include all labor, material and equipment, and the overhead and profit of the general contractor and subcontractors.
- Remoteness:
  Due to the type of construction and proximity to urban areas, the remoteness factor would be less than one percent and is therefore not included in calculations.
- Mobilization:
  This item consists of furnishing all bonding, licensing, plant, labor, materials and equipment necessary to mobilize the contractor's equipment to the project site and, upon completion of the work, to demobilize the equipment from the site. Based on experience, five percent (5%) of the construction cost will be used.

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*The Construction Cost Summary, Table 4-1, does not include design services. Information for design services and cost allowances are included in Table 4-2, item 12.

- Construction Contingency:
  A ten percent (10%) contingency factor is used to account for unforeseen conditions and changes during the remaining engineering phases, also for changes encountered during construction.

- Design Services-Design Contingencies:
  An allowance must be provided for design, construction observation, operations and management manuals and design contingencies. Due to the indeterminate nature of the final design elements, only approximations can be made to indicate the range of costs. Due to all elements being dependent to some degree on the support systems, clear separation of the programs with their portions of the cost of the support systems is not reasonable at this time. Therefore, it is recommended that preliminary professional services costs and fees be determined for the selected programs and that these then be added to the construction cost estimates to determine the project costs.

TABLE 4-1

CAPITAL COSTS
(CONSTRUCTION COST SUMMARY)

SUPPORT SYSTEMS:			
SITEWORK	107,110		
UTILITIES	43,500		
PUMP STATION	224,000		
HEAT EXCHANGER BUILDING	629,800		
SUPPORT SYSTEMS	258,300		
WASTEWATER TREATMENT	140,000		
		1,402,710	
AQUACULTURE PROGRAM			
AQUALAB	415,300		
COMMERCIAL FISH HATCHERY	786,000		
		1,201,300	
HORTICULTURE PROGRAM			
HORTICULTURE SERVICE BUILDING	134,000		
GREENHOUSES	40,000		
METHANE GENERATOR	40,500		
		214,500	$ 2,818,510
MOBILIZATION 5%	140,930		+ 422,780
CONTINGENCY 10%	281,850		
			$ 3,241,290

Cost estimate reflects a bid date of autumn 1977 and is related to the Engineering News Record (ENR) Const. Cost Index of 2532 for Boston. It relates to a whole integral design concept described within the text and drawings and is based only on the drawings and details shown. Other uses of this estimate (such as extrapolations or uses in part) can result in misleading results.

TABLE 4-2

CAPITAL COST ESTIMATE (1977 dollars)
(UNIT COSTS)

ITEM	QTY.	UNIT	UNIT COST $	COST $
1. Sitework				
Grading		TOT.		31,470
Erosion control	74,560	SF	.03	2,240
Soil treatment	1.84	ACRE	1300	2,390
Landscaping and signs		TOT.		8,000
Fencing	920	LF	8.40	7,730
Pavement	7,120	SF	7.00	49,840
Drainage	60	LF	24.00	1,440
Site Lighting		TOT.		4,000
				107,110
2. Utilities				
Wells	2	TOT.		13,500
Septic tank & drain field	2	EACH	5000	10,000
WWT drain field	1	EACH	7500	7,500
Electrical service		TOT.		12,000
Telephone		TOT.		500
				43,500
3. Pump Station				
Substructure and superstructure		TOT.		100,000
Mechanical				
Gates		TOT.		10,000
Travelling screen		TOT.		70,000
Pumps		TOT.		31,000
Piping & valves		TOT.		11,500
Electrical		TOT.		2,500
				225,000

(continued)

	ITEM	QTY.	UNIT	UNIT COST $	COST $
4.	Heat Exchanger Building				
	Building shell	4,275	SF	40.00	171,000
	Mechanical				
	Heat exchanger		TOT.		326,000
	Pumps, mounting & installation (4)		TOT.		42,000
	Standby generator, 400 KV		TOT.		45,000
	Piping & Valves		TOT.		25,000
	Electrical		TOT.		5,800
	Furnishings & special equipment		TOT.		15,000
					629,800
5.	Aqualab				
	Building shell	6,600	SF	37.00	246,000
	Mechanical				
	Piping & valves		TOT.		99,300
	Tanks		TOT.		18,500
	Electrical		TOT.		18,500
	Furnishings & special hatchery equipment		TOT.		35,000
	Vehicles & rolling stock		TOT.		12,500
	Heating, ventilation, air-conditioning		TOT.		4,000
					433,800
6.	Commercial Fish Hatchery				
	Building shell	18,000	SF	25.00	450,000
	Mechanical				
	Piping & valves		TOT.		133,000
	Raceways	8	EACH	17,250	138,000
	Electrical		TOT.		10,500
	Furnishings & special equipment		TOT.		30,000
	Vehicles & rolling stock		TOT.		12,500
	Heating, ventilation air-conditioning		TOT.		12,500
					786,000
7.	Horticulture Service Building				
	Building shell	4,000	SF	25.00	100,000
	Mechanical				
	Piping & valves		TOT.		5,000
	Electrical		TOT.		9,000
	Furnishing & special equipment		TOT.		5,000
	Vehicles & rolling stock		TOT.		12,000
	Heating, ventilation air-conditioning		TOT.		3,000
					134,000

(Continued)

	ITEM	QTY.	UNIT	UNIT COST $	COST $
8.	Greenhouses				
	4 complete greenhouses (See Appendix for cost breakdown)		TOT.		40,000
					40,000
9.	Methane Generator				
	Structure		TOT.		28,500
	Mechanical				
	Piping & valves		TOT.		10,000
	Electrical		TOT.		2,000
					40,500
10.	Support Systems				
	Plant discharge water piping		TOT.		68,700
	Heated ambient water piping		TOT.		121,700
	Raw ambient water piping		TOT.		49,500
	Wastewater discharge piping		TOT.		8,400
	Monitor & alarm systems		TOT.		10,000
					258,300
11.	Wastewater Treatment				
	Pretreatment		TOT.		60,000
	Polishing pond	3,200	SF	2.50	80,000
					140,000

12. Design Services and Contingencies

Based upon the conceptual system's preliminary construction estimates above, the following is provided for guidance in estimating project completion funding. Please note these are approximations subject to final project definition and scoping.

Program Element	Design Allowance	Construction Allowance	O&M Manual Preparation	Total Allowance
- Support System	$150,000	$ 60,000	$ 50,000	$260,000
- Aquaculture Program	145,000	50,000	70,000	265,000
- Horticulture Program	40,000	10,000	20,000	70,000
- Special Services, etc.	75,000			75,000
	$410,000	$120,000	$140,000	$670,000

4.2 OPERATION AND MAINTENANCE COSTS (Table 4-3)

The following estimate of operation and maintenance costs is based on Fall 1977 prices. A mark-up for inflation will be required when the construction date is known.

Other important factors of this estimate are:

- The O & M costs for the aqualab are for a full year, while the costs for the hatchery are for nine months.
- The estimated pumping cost for the aqualab may be high. Additional engineering has been done on the heat exchangers, which indicates these costs may be about 25% too high.
- The maintenance costs include a facility replacement cost equal to 2% of the capital cost of the facility.

TABLE 4-3

OPERATION & MAINTENANCE COSTS

	Aqualab (12-month operation)	Hatchery (9-month operation)	Greenhouse & Service Building (12-month operation)	Methane Generator (12-month operation)	TOTAL
Water Pumping (0.015/kwh)	$ 27,000	$ 23,500	$ 150	$ 50	$ 50,700
Boiler Heating					
Stand-by	11,000	0	0	0	11,000
20-Day Scram	37,500	0	0	0	37,500
Building Utilities	3,000	12,000	3,000	600	18,600
Supplies (incl. feed)	7,000	40,000	4,000	0	51,000
Insurance (auto,fire,etc.)	2,000	3,000	300	0	5,300
Maintenance @ 2%/yr (vehicular, building, etc.)	28,000	26,000	6,000	500	60,500
Labor					
Manager	12,500	12,000	12,000	0	36,500
Assistants	10,500	18,000	9,000	600	38,100
TOTALS	$138,500	$134,500	$34,450	$1,750	$309,200

APPENDIX A

FEDERAL LAWS AFFECTING VERMONT YANKEE WASTE HEAT PROJECT

H. Reed Witherby

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The healthiness of food products in interstate commerce trade could be a problem (2). Vermont has a parallel but not identical statute covering intrastate products, which will be touched upon later. The application of the FDCA requires some close legal analysis and some understanding of the operation of Vermont Yankee and of the proposed project.

A. Scope of the Food, Drug and Cosmetic Act (FDCA)

In general, the FDCA regulates unhealthy foods by excluding from commerce foods deemed to be adulterated. A threshold question is whether the planned project will be within the interstate commerce clause, which generally has broad reach. Although cases dealing with the interpretation of "interstate commerce" under the FDCA all involve business activity, "commerce" for the purposes of commerce power need not be business activity (3). The "Court" held that cattle ranging across state borders were within interstate commerce even though the cattle were not driven across the border, no instrumentality of interstate commerce was used, and no commercial purpose was involved in the border crossing. Fish introduced into the Connecticut River are sufficiently analogous to the cattle (Reference 3) to suggest that, even if the products of the Vermont Yankee Waste Heat Project are not sold commercially, they could be considered to be in interstate commerce.

B. FDCA Statutory Scheme - An Overview

Analysis of the effect of the FDCA on the Vermont Yankee Waste Heat Project requires a general understanding of the Act. This is not easily achieved, as the FDCA is made up of different, sometimes overlapping legislation.

The first prohibition (dating from the Food and Drug Act of 1906) is of food "bearing or containing any poisonous or deleterious substance" (natural or added) which may render the food injurious to health. Thus, if a particular batch of fish or vegetables were contaminated so as to be unhealthy, it would not be marketable. The burden is on the government to prove that the particular food product, by itself, poses a health hazard (4).

In 1938, the Food, Drug and Cosmetic Act introduced a prohibition of "any poisonous or deleterious substance added to food, except where such substance is required in the production thereof or cannot be avoided by good manufacturing practice..."(5). This prohibition was interpreted rigidly to ban all unnecessary substances which the government could show to be poisonous or deleterious as such, even though used in amounts which could not possibly render the product unsafe (although there was an extra-legal system of informal use tolerances) (6,7). If an added unhealthy substance was found to be necessary, the government was supposed to set tolerance limits (taking into account cumulative effects beyond the particular item of food involved) within which the additions were considered safe. The Food Additives Amendment of 1958 has now limited this category to "added poisonous or added deleterious substances (other than...food additives)" (8). Since the comprehensive definition of food additives includes poisonous or deleterious substances except when added on an accidental basis (see below) and since the accidental addition of poison is unlikely to be considered necessary to, or unavoidable in, food production, it is not clear whether this category retains any viability; but see part I.D. below.

Finally, further prohibitions were incorporated by the Food Additives Amendment of 1958. In general terms, this amendment disallows the presence of additives in food, or the subjection of food to radiation, without the blessing of a Food and Drug Administration regulation upon a petition in which the applicant must demonstrate that the intended use is safe under the proposed conditions. Further, the 1958 amendment introduced the so-called Delaney Clause, flatly prohibiting the addition to food of any carcinogen in any amount.

C. Regulation of Food Additives

The Food Additives Amendment of 1958 requires a Food and Drug Administration regulation or exemption with respect to any food additive, defined as:

> any substance the intended use of which results or may reasonably be expected to result, directly or indirectly in its becoming a component or otherwise affecting the characteristics of any food (including any substance intended for use in producing, manufacturing, packing, processing, preparing, treating, packaging, transporting or holding food; and including any source of radiation intended for any such use), if such substance is not generally recognized, among experts qualified by scientific training and experience to evaluate its safety, as having been adequately shown through scientific procedures (or, in the case of a substance used in food prior to January 1, 1958, through either scientific procedures or experience based on common use in food) to be safe under the conditions of its

> intended use (with certain exceptions not presently relevant) (9).

According to the legislative history of the Food Additives Amendment of 1958, this provision

> covers substances which are added intentionally to food. These additives are generally referred to as "intentional additives". The legislation also covers substances which may reasonably be expected to become a component of any food or to affect the characteristics of any food. These substances are generally referred to as "incidental additives" (10).

The legislative history also draws a distinction between these "intentional" or "incidental" additives and "accidental additives". The latter are defined as "substances (which) if properly used may not reasonably be expected to become a component of food or otherwise affect the characteristics of a food" (11).

The 1958 Amendment also requires a Food and Drug Administration regulation or exemption for "intentionally subjecting food to radiation" (12). There is no requirement that radioactivity affect or become a component of the food.

The Food Additives Amendment accordingly requires a regulation or exemption from the Food and Drug Administration for the use of circulating water in the waste heat project if subjection of fish or produce to radiation is intentional or if any substances affecting the products are intentional or incidental additives not generally recognized as safe. Exemptions are available only for scientific testing. Regulations are available only upon a petition in which the applicant undertakes to establish, upon scientific data, the safety of the proposed additive under the conditions of proposed use (13). The key provision, containing the proviso known as the Delaney Clause, is (14):

> No such regulation shall issue if a fair evaluation of the data before the Secretary fails to establish that the proposed use of the food additive, under the conditions of use to be specified in the regulation, will be safe: Provided, that no additive shall be deemed to be safe if it is found to induce cancer when ingested by man or animal, if it is found, after tests which are appropriate for the evaluation of the safety of food additives, to induce cancer in man or animal.

There is an exception to the proviso with respect to animal feeds in that no additive residue will remain in the ultimate food product. Although the practical situation of some possible contaminants in the growing environment projected here is certainly analogous, it is unlikely that this exception would apply here.

The Delaney Clause has come under considerable criticism because it forbids the government to weigh the possible public health benefits from low-level use of any substance which is found to be carcinogenic under any conditions. The scientific anomalies of this provision are explored in reference 15.

i. Radioactivity

Much concern has been expressed during the development of the waste heat proposals about the limiting effects of the Delaney Clause with respect to the Vernon station's nuclear character. It can be generally assumed that all radioactivity is, at some level, carcinogenic. However, there is no basis for concluding that radioactivity will become a food additive at Vermont Yankee under the proposed circumstances.

The radioactivity at Vernon emanates from the nuclear fission material at the core of the plant. It is predictable that failures in the cladding of this material will allow neutron emissions into the surrounding primary coolant, causing small amounts of qualitatively less potent radioactivity in that closed system. The plant is designed, however, so that none of this radioactivity should get into the circulating water. The exchange of heat between these two systems in the condenser occurs through two thicknesses of pipe which allow no transfer of materials, and would not be of a variety capable of causing any radioactivity in the circulating water.

Moreover, instead of discharging this induced radioactivity into the river (as permitted by the terms of its Nuclear Regulatory Committee and Federal Water Pollution Control Agency permits), Vermont Yankee has chosen to dispose of it otherwise. Radioactive inert gases are bled from the primary coolant and released into the atmosphere; radioactive corrosion products are filtered out and transported away for burial; and tritium is stored in tanks to decay. Even if the plant were to discharge such items through its "radwaste" system, that system is not mixed with the circulating water system until the brink of discharge into the river; that is, the water for the proposed projects would be drawn out of the circulating water system at a point prior to the entry of any discharge of radioactive contaminants through the radiological decontamination system.

Thus, quite apart from the extra barrier which could be provided by a surface type exchanger, it should be clear that there will be no intentional subjection of the food to radiation, making reference 16 inapplicable to the project. The only way radionuclides could get into the water circulating to the proposed projects would be from a failure in the condenser;

such a failure would be unintentional; therefore, the resulting possibility of exposure would be unintentional. (The legal doctrine which in some contexts holds someone to "intend" the foreseeable consequences of his actions would appear inappropriate here. First, the definition of food additive expressly includes this variety of intention in its coverage of "incidental additives", raising the inference that the omission of an explicit inclusion here was intended as an exclusion. Secondly, the statutory language (16) prohibits "subjecting" the food to radiation, phrasing which imports a positive act of directing radiation upon the food.)

A similar analysis applies to the question whether radioactivity could under any circumstances be an "intentional additive" under reference 17. The statutory definition includes "any substances the intended use of which results or may reasonably be expected to result" in its becoming a component of or affecting the food (18). It is Vermont Yankee's clear intention not to expose the food to radioactivity; under the conditions of its intended use, radioactivity will not enter the circulating water at all. Although the words of the statute may admit of some ambiguity, the natural interpretation applied above is verified by the legislative history, in which "intentional additives" are defined as "substances which are added intentionally to food". Under the circumstances presented, radioactivity is clearly not such a substance.

The question remains whether radioactivity might be an "incidental additive", that is, a substance "which may reasonably be expected" to become a component of or affect the fish or vegetables. The legislative history contrasts such included substances with "accidental additives", substances which "if properly used may not be reasonably expected to become a component..."(19) (emphasis added). Proper functioning of the Vernon plant, as it is designed, will not result in the presence of radioactivity in the circulating water. Any introduction of radioactivity into the water would be the result of a failure in the system. Thus under this definition, radioactivity could not be an "incidental additive".

The statutory standard of reasonable expectation is to some extent a function of probabilities. Thus, if experience at the plant showed that failures in the condenser were frequent, so that it was reasonable to expect the presence of radioactive contamination in the circulating water, then further steps of analysis concerning heat exchangers, whether exposure would result in contamination, and possible general recognition of safety could be necessary. However, the experience of the Vermont Yankee plant has been that over five years of operation only one leak of radioactivity into the circulating water has occurred (due to the rupture of a gasket in March, 1977). This statistic supports the conclusion that any presence of radioactivity in the circulating water would properly be considered an accident rather than an incident to proper operation.

Thus, it should be concluded without further analysis that radioactivity from the plant will not be a "food additive" with respect to any of the products of the proposed projects. (However, the analysis considered below with respect to chemicals could also be applied: e.g., the presence of heat exhangers would reduce considerably the statistical probability of exposure, supporting the determination that any radioactivity would be an "accidental" additive. Moreover, it is understood that at least tritium would pass through rather than accumulate in fish, etc.) The situation at other nuclear plants may be different. For example, the Northeast Utilities plant at Millstone (intentionally) discharges its radioactive wastes into the growing environment of its mariculture experiment. The application of the "food additives" provision to that situation (apart from the possible lack of interstate commerce) would appear to turn primarily upon whether the resulting concentrations of radioactivity in the oysters produced could be shown to be generally recognized as safe by scientific experts. (The highest concentrations measured at Northeast Utilities, under circumstances more likely to produce high concentrations than would similar discharges at Vermont Yankee, were on the order of a few percentage points over background; therefore, given the variation in background radiation from place to place, these concentrations are probably well below those naturally occurring in much of the food that we eat (20). The fact that the Delaney Clause would prohibit the Food and Drug Administration from finding radioactivity to be safe within any tolerances with respect to authorizing its use as a food additive does not legally affect the analytically prior determination of whether it is generally recognized as safe under the conditions of its intended use; because if it is so recognized, it is not a food additive and therefore does not come under the Delaney Clause.

ii. Chemicals and Corrosion Products

Two categories of substance *are* added to the river water as it circulates through the Vernon plant and will be contained in the circulating water which is drawn off to the proposed projects. These are (a) chemicals added as cleaning agents, demineralizers, biocides and corrosion controllers and (b) corrosion products from the pipes through which the water runs. Will these constitute "food additives" requiring a Food and Drug Administration regulation?

The legislative history uses as an example of accidental additives "paints or cleaning solutions used in food processing plants". This example may appear virtually on all fours with the chemicals used at Vermont Yankee since their purpose is analogous to cleaning solutions. However, at Vermont Yankee the chemicals are added intentionally to the very circulating water which will carry the heat to the project and, absent heat exchangers, will come into direct contact with the food. Indeed, it is partly because of the potential deleterious effects of such direct contact that biologists working on the aquaculture project have recommended the use of heat exchangers. Assuming that such contact would result in chemicals becoming a component or affecting the characteristics of the resulting food product (which seems likely), the next question would be whether such chemicals could be shown to be "generally recognized as safe" under these conditions.

Presumably this determination would vary with respect to Vermont Yankee's use of particular chemicals. (Cf. EPA effluent limitations as to steam generating nuclear plants... reference 21.) However, general recognition of safety under conditions of intended use is not easily satisfied, requiring a consensus of experts based upon scientific testing or (as to substances used in food prior to 1958) upon experience based upon common use in food.

Without heat exchangers, the "generally recognized as safe" standard would also have to be satisfied with respect to pipe corrosion residues. (This item highlights the impact of advancing technology which now can measure small amounts that would have gone undetected only a few years ago.) This material is not intentionally added to the circulating water, but it should reasonably be expected to get into that water in small quantities, even under normal and proper use of the plant. If this results in its becoming a component of or affecting the food, only a general recognition of safety would prevent it from being a food additive.

Perhaps as to some of the chemicals or corrosion products, some testing has occurred (reference 22) or perhaps it could be determined that greenhouse or hatchery operations predating 1958 introduced the same substances to their products, constituting an identifiable experience of common use upon which a scientific judgment of safety could be based. If not, and if no heat exchangers are used, it would appear to be necessary to conduct tests and (unless the tests gave rise to a "general recognition of safety") to seek a Food and Drug Administration regulation setting conditions for use. The alternative to this is to use heat exchangers.

Heat exchangers change the "food additives" analysis by constituting a barrier between the circulating water and the growing environment, a barrier which may, in addition, be pressurized to cause any leaks to be directed away from the food environment into the circulating water. Since the purpose of such a barrier includes such protection, it may be said with confidence that neither the chemicals nor the corrosion products would be reasonably expected to be exposed to the food and, therefore, that they would not be "food additives" within reference 23. (This would apply also to any radioactivity which found its way into the circulating water, whether expectably or not.) It is understood that heat exchangers are projected for the entire aquaculture project and contemplated for three of the four greenhouse designs. Moreover, the remaining greenhouse ("Rutgers' Design") is, for environmental reasons, being recommended for raising ornamental plants rather than food plants, and the lack of a heat exchanger there would be of no legal significance if that recommendation is followed.

In sum, given the presence of heat exchangers isolating the circulating water from each proposed food-growing environment, none of the items under consideration would be "food additives" requiring a Food and Drug Administration regulation.

D. Other Food and Drug Provisions

In distinguishing accidental additives from intentional and incidental additives, the legislative history of the Food Additives Amendment states that "if accidental additives do get into food, the provisions of the (FDCA) dealing with poisonous and deleterious substances would be applicable" (24). In sections of the FDCA which mention "poisonous and deleterious substances" are those (referred to in the overview above) which predated the 1958 Amendment.

Food containing substances which are poisonous or deleterious such that it may be injurious to health is adulterated (unless the substance is not "an added substance" and the quantity of the poisonous or deleterious substance in the food does not ordinarily make it injurious to health) (25). Thus, a specific batch of actually unhealthy food would be covered.

The section of reference 26 which provides that an added substance (other than a food additive) which is poisonous or deleterious is safe only if, under reference 27, the substance is "required in production (of food) or cannot be avoided by good manufacturing practice", and then only pursuant to tolerances established by the Food and Drug Administration (28). It could be argued in this respect that the use of a heat exchanger was required in the waste heat project as "good manufacturing practice" under the circumstances. Although a heat exchanger is expensive, it is readily available technology which could prevent addition to fish or produce substances, including radioactivity, biocidal chemicals and corrosion inhibitors, which might otherwise result in adulteration. If so, the use of heat exchangers could be required in order to avoid the prohibition of reference 27 as to any substances which might accidentally get added to the food.

Assuming the presence of heat exchangers, however, there could still be failures which allowed, toxic chemicals into the growing environment. If as a result traces of such chemicals found their way into the food, the literal terms of reference 27 would prohibit the introduction of that food into interstate commerce without the existence of a tolerance promulgated by the Food and Drug Administration. Presumably, at this point, some practicability of approach may take over for de minimis additions; the Food and Drug Administration also has a system of informal tolerances under this section (29). It should be remembered that this section applies only to added substances which are poisonous or deleterious.

Other provisions of the FDCA declare food which is filthy or decomposed, or the product of a diseased animal, or the like, to be adulterated. These prohibitions would be relevant to the actual day-to-day operation of the project, but do not present limitations upon the design of the project.

Consideration should also be given to the possible presence of contaminants in the upstream river water which is contemplated as the heat carrier to the growing environment if heat exchangers are used. It has been held that mercury in swordfish is an "added substance" within the meaning of reference 25 on the theory that it does not occur naturally in the fish, but is acquired through its external food supply (30). Similarly, the presence in fish of DDT has been held to support seizure, once the fish were smoked, as a food additive (31). Pesticides on raw agricultural products are governed separately under the FDCA (31), and tolerances have been promulgated (32).

Vermont's Labeling of Foods, Drugs, Cosmetics and Hazardous Substances Act (33) prohibits the adulteration of any food within the state (34). Adulterated food is defined in reference 35 in terms parallel to the FDCA prior to the 1958 Amendment. Thus, food is adulterated if it contains a poisonous or deleterious substance which may render it injurious to health. If the substance is added, it adulterates the food unless it is required in production, in which case the state authorities should promulgate tolerance (36). This act should not apply to the extent that provisions of it conflict with the FDCA.

II. EPA RESTRICTIONS AND PERMIT REQUIREMENTS

A. Aquaculture Regulations

One section (37) authorizes the Administrator of the EPA "to permit the discharge of a specific pollutant or pollutants under controlled conditions associated with an approved aquaculture project under Federal or State supervision". Subsection (b) of Section 318 empowers the Administrator to establish procedures and guidelines which he deems necessary to carry out Section 318 (37). The EPA has promulgated regulations pursuant to this provision (38).

These regulations do not apply to the Vermont Yankee aquaculture project. The scope of the aquaculture regulations is limited "to those projects which are located in navigable waters..." (39). The regulations defined "aquaculture project" as "a defined managed water area which uses discharges of pollutants into the designated project area" (40): "designated project area" is in turn defined as "those portions of the navigable waters within which the applicant...proposes to confine the cultivated species" (41). Also, the Supplementary Information accompanying the promulgation of the regulations states that "aquaculture activities not covered by these regulations are those facilities operated in ponds, silos, and other structures not within the navigable waters." (38). The Vermont Yankee hatchery is to be located in a separate building outside the Connecticut River, and therefore falls within the category of "structures not within navigable waters", and is not subject to the requirements of a permit under Section 318 of the FWPCA.

B. Pollution Discharge Permits

Section 402 of the Federal Water Pollution Control Act (FWPCA) (42) establishes the National Pollutant Discharge Elimination System (NPDES). This provision authorizes the Administrator of the EPA, or, where applicable, the appropriate state permit-granting authority, to issue a permit for the discharge of any pollutant into navigable waters, provided doing so meets statutory conditions (43). Although "approved aquaculture projects" are excluded from this requirement (44), other "discharges from an aquatic animal production facility" are specifically included in the requirement of an NPDES permit (45). Since the present project is not subject to regulations governing aquaculture projects but is involved in production of aquatic animals, it would constitute a point source from which the discharge of pollutants requires an NPDES permit. A pollutant within the meaning of the FWPCA includes, inter alia, solid waste, chemical waste, biological materials, radioactive materials, and heat (46). Since the fish tanks would discharge heat, fish waste and food residues (and possibly contaminants from the circulating water system) into the Connecticut River, an interstate waterway, the aquaculture project involves discharge of pollutants into navigable waters and requires a permit. As the result of an agreement between the EPA and State of Vermont, the NPDES program administration is delegated to the Department of Water Resources of the Vermont Agency of Environmental Conservation (47). Full guidelines for state permit requirements are set out (48).

III. NRC LICENSING REQUIREMENTS

A. Modification of Existing Use and Production Permit

Vermont Yankee must obtain modification of its NRC license in order to use its waste heat in either project, if this use is inconsistent with procedures described in the facility's safety analysis report to the NRC, if the change in the disposal of circulating water does involve a change in the technical specifications incorporated in Vermont Yankee's license, or if the change presents an unreviewed safety question (49). The change will be deemed to present an unreviewed safety question if it will increase the probability of the occurrence or the consequences of an accident, or if it creates the possibility of an accident or a malfunction of a different type than any previously evaluated (50). Vermont Yankee nevertheless would be required to maintain records of the changes to the facility and resultant changes in procedures and to prepare a written safety evaluation of the change demonstrating that the latter does not present an unreviewed safety question. A description of the change and the safety evaluation must be furnished to the NRC Regional Office (51). It would appear that a change in the specifications of the circulating water discharge system will require a license amendment even if Vermont Yankee sees no safety problem, because the activity affects the environmental technical specifications.

B. NRC Environmental Review

The National Environmental Policy Act of 1969 requires all Federal agencies to prepare detailed environmental impact statements on major federal actions affecting the quality of the environment (52). The NRC's policies and procedures for such environmental review in connection with the agency's licensing and regulatory activities are set out in reference 53. These regulations require preparation of an environmental impact statement in connection with, *inter alia*, any action which the Commission determines is a *major* Commission action significantly affecting the quality of the human environment (54). Included among actions considered to be major Commission actions significantly affecting the quality of the human environment is any permit or license amendment which "would authorize a significant change in the types or significant increase in the amounts of effluents..." (55).

The FWPCA vests primary jurisdiction for the control of water pollution in the Environmental Protection Agency (56). Recognizing this, the NRC requirements for environmental review are made subject to the limitations contained in an interim policy statement published (57). This "second memorandum of understanding and policy statement" states that with respect to water quality standards, maximum daily limits for pollutants and thermal limits the NRC will not impose different limitations or requirements as a condition to any permit or license from those imposed by environmental agencies, although the NRC did reserve the option to impose more stringent limitations or requirements than those imposed pursuant to the FWPCA. In addition, the NRC declaration of policies states that no alternative pollutant discharge systems will be considered by the Commission where a permit has been received or effluent limitations imposed pursuant to the FWPCA. Thus, with respect to pollution control considerations stemming from the aquaculture project, it appears that the NRC's environmental review yields to NPDES permit requirements, even where the NRC might otherwise impose more stringent standards.

The NRC, however, considers effluent limitations for nuclear material to remain within its primary jurisdiction. NRC's environmental review of any change in the Vermont Yankee discharge system may therefore be required. Although the aquaculture and horticulture projects will not result in any additional radiological discharge, the proposed uses of condenser effluent may result in hazards from the accidental discharge of effluents into unrestricted areas not previously reviewed by the NRC. It therefore seems advisable to seek NRC's review. Such review will not necessarily require filing of an environmental impact statement. If, upon evaluation of the proposed action, the NRC determines that an environmental impact statement need not be prepared, it may issue a "negative declaration" explaining why an environmental impact statement is not required and that a general environmental appraisal will be made (58).

IV. CONCLUSIONS

Since the use of nuclear power plant waste heat for aquaculture and horticulture is very recent, there is little law which directly establishes standards applicable to the Vermont Yankee Waste Heat Project. The requirements affecting the project are chiefly case-by-case permit requirements of the Environmental Protection Agency and the Nuclear Regulatory Commission.

The planned discharge of pollutants into the Connecticut River will require a National Pollutant Discharge Elimination System permit from Vermont authorities. This will be a "new source" and therefore requires environmental review. Amendment of Vermont Yankee's Nuclear Regulatory Commission license will be required because of the detailed specifications in that license for discharging circulating water.

The precise application of the Food, Drug and Cosmetic Act depends largely upon whether surface heat exchanger systems are used and, if they are not, upon the probability that the circulating water will contain potentially unhealthy substances. If heat exchangers _are_ used, as is generally contemplated, the

FDCA will not apply unless food accidentally becomes contaminated with poisonous or deleterious substances. If heat exchangers are not used, the Delaney Clause setting zero tolerance levels for carcinogens will still not be implicated to the extent that contamination is not to be expected, despite the fact that Vermont Yankee is a nuclear station; but a regulation or control may be required for certain chemicals or pipe residues contained in the cooling water. The Food, Drug and Cosmetic Act also is implicated if particular food produced at the project becomes contaminated so as to present a health hazard.

REFERENCES

1. Federal Food, Drug and Cosmetic Act, 1938.

2. Ibid, 21 USC § 301 et. seq.

3. Maryland v Wirtz, 269F. Supp. 826, 832-33 (D.Md. 1967), aff'd 392 U.S. 183 (1968) and Thornton v. United States 271 U.S. 414, 425 (1926).

4. Federal Food, Drug and Cosmetic Act. § 342(a)(1). See United States v. Lexington Mill & Elevator Co., 232 U.S. 399 (1914).

5. Ibid. § § 342(a)(2)(A), 346.

6. Markel, The Food Additives Amendment of 1958, 14 The Business Lawyer 514 (1959).

7. United States v Ewig Bros. Co., 502 F. 2d 715 (7th Cir.1974).

8. Federal Food, Drug and Cosmetic Act. § 342(a)(2)(A).

9. Ibid, 21 USC § 321(s).

10. S. Rep. No. 2422, 85th Cong., 2d Sess., 1958 U.S. Code Cong. & Admin. News 5303-04.

11. Ibid. 5304.

12. Federal Food, Drug and Cosmetic Act. 21 USC § 342(a)(7).

13. Ibid, § 348 and 21 C.F.R. Part 171.

14. Ibid, § 348(c)(3).

15. The Delaney Clause: Technical Naivete and Scientific Advocancy in the Formulation of Public Health Policies, 62 California Law Review 1084 (1974).

16. Federal Food, Drug and Cosmetic Act, § 342(a)(7).

17. Federal Food, Drug and Cosmetic Act, § 321(s) and 342(a)(C).

18. Ibid. § 321(s).

19. S. Rep. No. 2422, supra, at 5304.

20. Cf. Section 1412 of the Public Health Service Act, as amended by the Safe Drinking Water Act, 42 USC § § 300 g-1, 300 g-3, 300 j-4 and 300 j-9 and the EPA national interim primary drinking water regulations, 40 C.F.R. Part 141.

21. Cf. EPA, 40 C.F.R. Part 423, 423.11(j) proposed EPA effluent standards for toxic pollutants under 33 USC 1317(a)(1), 38 Fed. Reg. 35388 (1973).

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22. Ashley, G.C. & J.S. Hietala. The Sherco Greenhouse: A Demonstration of the Beneficial Uses of Waste Heat. Proc. of Conf. on Waste Heat Management & Utiliz., 5/9-11, 1977, Miami Beach, Fl.

23. Federal Food, Drug and Cosmetic Act § 342(a)(2)(C).

24. S. Rep. No. 2422, supra, at 5304.

25. Federal Food, Drug and Cosmetic Act § 342(a)(1).

26. Ibid. § 342(a)(2)(A).

27. Ibid. § 346.

28. FDA. Sec. 21 C.F.R. Part 122.

29. United States v. Ewig Bros. Co. 502 F.2d, 715, 720 (7th Cir. 1974).

30. United States v. An Article of Food Consisting of Cartons of Swordfish, 395 F. Supp. 1184 (S.D.N.Y. 1975) but see Note 85 Harv. L. Rev. 1025 (1972).

31. Ewig Bros. supra. Pesticides on raw agricultural products are governed separately under the FDCA, see § § 342(s)(2)(B), and 346(a).

32. 21 C.F.R. Part 193.

33. Vermont's Labeling of Foods, Drugs, Cosmetics and Hazardous Substances Act, Title 18 V.S.A. § § 4501 et seq.

34. Ibid. § 4502.

35. Ibid. § 4059.

36. Ibid. § 4062.

37 Federal Water Pollution Control Act, Section 318, 33 USC, § 1328.

38. 42 Fed. Reg. 25,478 (1977) to be codified at 40 C.F.R. § 115.1 et seq.

39. Ibid. § 115.2(d).

40. Ibid. § 115.1(d).

41. Ibid. § 115.1(e).

42. Federal Water Pollution Control Act, Section 402, 33 USC. § 1342.

43. Ibid. 33 USC § 1342(a)(1), (b).

REFERENCES

44. 40 C.F.R. § § 124.21(c) and 125.4(c).

45. 40 C.F.R. 124.21(g)(2) and 125.4(i)(2), as amended, 41 Fed. Reg. 28496 (1976).

46. 33 USC § 1362 (6).

47. 2 State Water Regs. 93:0581 (BNA) (1974).

48. 40 C.F.R. § 124.1 et seq.

49. 10 C.F.R. § 50.59(a)(1).

50. 10 C.F.R. § 50.59(a)(2).

51. 10 C.F.R. § 50.59(b).

52. 42 USC § 4332.

53. 10 C.F.R., Part 51.

54. 10 C.F.R. § 51.5(a)(10).

55. 10 C.F.R. § 51.5(b)(4).

56. 33 USC § 1251(d).

57. 40 Fed. Reg. 60115 (1975); cf. 10 C.F.R. 51.1(c).

58. 10 C.F.R. § 51.5(c)(1).

APPENDIX B

WASTE HEAT BOOSTING FOR ANAEROBIC FERMENTER EFFICIENCY IMPROVEMENT

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WASTE HEAT BOOSTING FOR ANAEROBIC FERMENTER EFFICIENCY IMPROVEMENT

Background

Bioconversion of photosynthetically fixed solar energy in existing agricultural residues has been projected to be capable of generating about one quad annually.* The obvious attraction of this possibility is that this is a clean renewable source of energy which would make use of animal wastes and other materials which have a pollutant creating potential. Energy farming has the capability of adding another 10 quads while generating several million tons of new protein in the form of bacterial cells. There are two objectives in this experiment. First, to examine the possibility of improving the rate of fermentation of animal residues by preheating the fermenting slurry with Vermont Yankee condenser discharge water and second to determine the economics of using the methane gas generated in the fermentation process as a substitute fuel for space heating. Technology for the generation of methane by animal residue fermentation has been developed for very large cattle operations (1000 animals or more), however, little work has been done on the development of economical anaerobic digesters for small scale farming applications (200 animals or less). Much of the quantitative data for these analyses has been reported in Jewell et al. (1976).

Historical Aspects

Anaerobic fermentation has been applied to sewage solids for digestion and stabilization for decades. However, until recently it has not been applied to animal wastes. To the best of these authors' knowledge, the first full scale methane generation system in the U.S. was built by a private company in Michigan in 1974. Presently, the U.S. DOE is involved in several large scale efforts to demonstrate the feasibility of adapting this technology to agriculture. A 3-million dollar demonstration plant is now under consideration for a 10,000-head beef feedlot operation, and Cornell University has been given authority to demonstrate the technology for dairies at its research facility in Harford, New York under the direction of William J. Jewell.

In general, methane fermentation of agricultural residues appears to be justified only in large scale operations (greater than 1000 head) if the net methane produced is the only benefit attributed to the system. Other potential benefits include:

1. Conservation of nutrients
2. Labor reduction
3. Odor control
4. Runoff control

---

*One quad is equal to 10^{15} BTU.

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It can be shown that when pollution control is needed with a liquid manure handling system, and all gas can be utilized, the fermentation system can generate energy at a very low cost even in dairies with 40 cows. The feasibility is site specific in the present state of knowledge.

Estimate of Agricultural Residues

One agricultural operation is located close to Vermont Yankee Nuclear Power Corporation's Vernon plant. This is Mr. Paul Miller's dairy which appears to be one of the most well operated, medium scale (200 cows) dairies in the Northeast U.S.

Table 2 summarizes the dairy manure production composition. These estimates assume that the waste is removed efficiently on a daily basis and that the animals are confined 100 percent of the time. Although Mr. Miller does not include the milking room wastewater, it would be possible to include this in the wastes. Bedding material used on the Miller dairy includes hay and limestone. If the manure was to be used in a fermenter, the use of limestone may cause some material handling problems and handling may have to be modified. Limestone is most often used to prevent animals from slipping on concrete surfaces.

The make-up of a dairy that would have about 100 milking cows at any one time would have the characteristics illustrated in Figure 1. The average daily waste composition is as follows for this size of operation:

TABLE 1

WASTE COMPOSITION

	kg/day
Total solids (87.8% water by weight)	8240
Total dry solids	1000
Volatile solids (82% total)	840
Total nitrogen	34
Ammonia nitrogen	18
Phosphorus	13
Potassium	29

The Miller farm has 200 cows with a capability for increasing its numbers up to double the above residue quantities, depending on the total numbers of animals on the farm. Note that the above values for the 100-cow dairy actually represent the residue generation from 163 cows, with only 100 being milked at any given time. Other sizes of dairy operations can be scaled up from these data.

TABLE 2

DAIRY COW MANURE PRODUCTION AND CHARACTERISTICS
(based on 1,000 pound liveweight)

Parameter	Unit	Total Excrement	
		Avg.	Range
Manure Production	kg/head/day	38.6	32.2-49.9
	(lbs/head/day)	(85)	(71-110)
Density	kg/ℓ	0.97	0.94-1.00
	(lbs/ft^3)	(60.6)	(58.6-62)
Total solids	% TS	12.5	-
	kg/head/day	4.81	3.08-6.76
	(lbs/head/day)	(10.6)	(6.8-14.9)
Volatile Solids	% TS	82	-
	kg/head/day	3.95	3.27-5.76
	(lbs/head/day)	(8.7)	7.2-12.7
$BOD_{5\text{-day}}$	kg/head/day	0.700	0.44-0.83
	(lbs/head/day)	1.55	0.98-1.84
COD	kg/head/day	4.81	2.63-7.26
	(lbs/head/day)	10.6	5.8-16
Total Nitrogen	% TS	3.9	-
	kg/head/day	0.19	0.16-0.28
	(lbs/head/day)	(0.41)	0.35-0.62
Ammonia Nitrogen	kg/head/day	0.10	-
	(lbs/head/day)	(0.23)	-
Total Phosphorus	% TS	1.5	
	kg/head/day	0.073	0.032-0.18
	(lbs/head/day)	(0.16)	0.07-0.39
Potassium	% TS	3.3	-
	kg/head/day	0.16	0.068-0.22
	(lbs/head/day)	(0.35)	(0.15-.48)

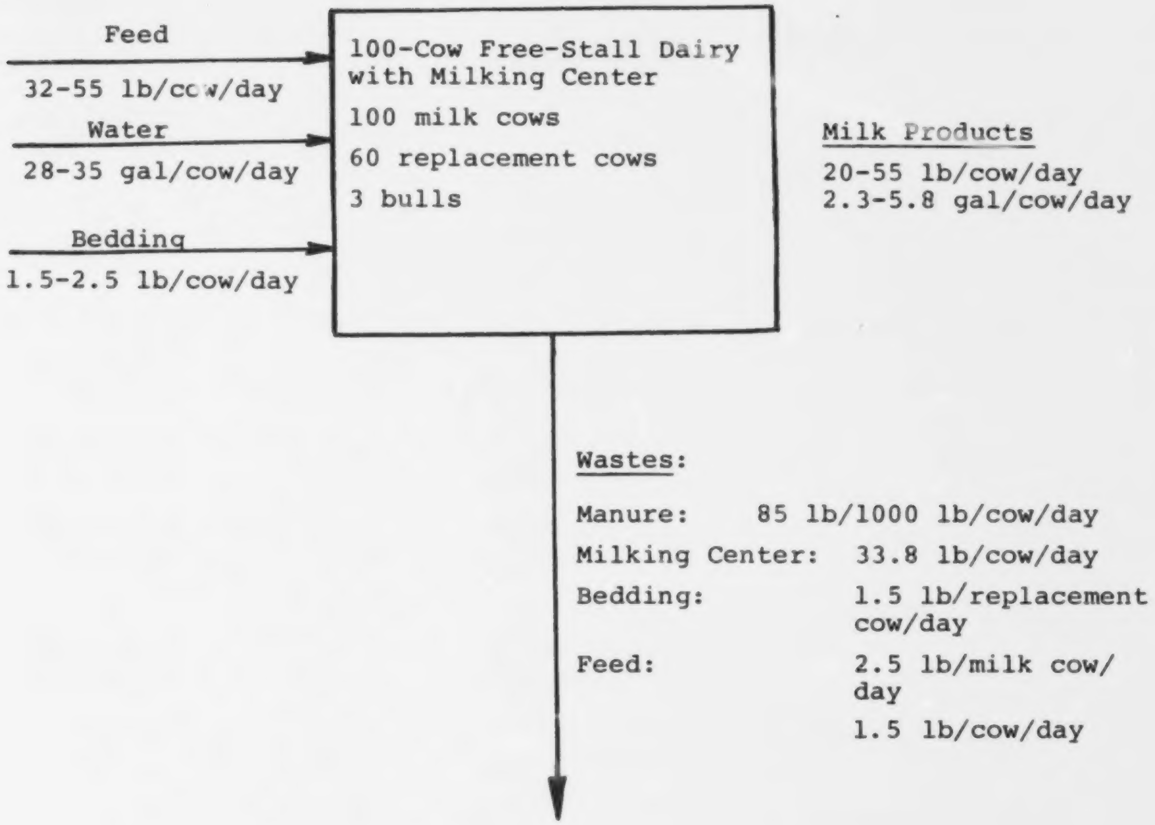

Feed
32-55 lb/cow/day
Water
28-35 gal/cow/day
Bedding
1.5-2.5 lb/cow/day
100-Cow Free-Stall Dairy with Milking Center
100 milk cows
60 replacement cows
3 bulls
Milk Products
20-55 lb/cow/day
2.3-5.8 gal/cow/day
Wastes:
Manure: 85 lb/1000 lb/cow/day
Milking Center: 33.8 lb/cow/day
Bedding: 1.5 lb/replacement cow/day
Feed: 2.5 lb/milk cow/day
1.5 lb/cow/day

Figure 1. Flow diagram of feed, milk production, and waste materials on a 100-cow, free-stall dairy.

Fermenter Design

The bacterial anaerobic fermentation process is a complex process. Many variables such as temperature, organic residence time, and solids retention period affect the feasibility of the process. One set of design criteria which would be successful when applied to dairy wastes is as follows:

Table 3

Characteristics of Anaerobic Fermentation Process

Waste volume generation rate for 100-milking cow operation	10.1 m^3/day (356.5 ft^3/day)
Premix tank volume	20 m^3 (706 ft^3)
Pumping rate (about)	0.2 m^3/min(3 gpm)
Reactor Design	
Hydraulic retention time	10 days
Temperature	35°C (95°F)
Solids loading rate	8.3 kg/m^3-day (0.5 lb/ft^3-day)
Total solids entering system	10% of slurry volume
Tank volume	124 m^3 (4377 ft^3)
Energy Production	
Volatile solids destruction	32% of slurry volume
Gas produced	223 m^3/day (7872 ft^3/day)
Methane content	65% of slurry volume

Energy Production Potential

As indicated in Table 3, the process operates at 35°C (95°F). Thus, in cold weather when the feed is coming into the reactor at 0°C (32°F), a substantial portion of the energy that is produced must be used to maintain the reactor temperature. The total production for the 100-cow dairy is estimated to be between 500 x 10^6 and 600 x 10^6 Kcal/year. The energy required to maintain reactor temperature amounts to 200 x 10^6 to 300 x 10^6Kcal/year, or up to half the total production when the reactors are not insulated well. By adding efficient insulation, this loss can be decreased to about 100 x 10^6Kcal per year, or about 20% of the produced gas. The added insulation, as polyurethane, costs about $6000. At a present market value of about $10 per 10^6Kcal ($2.50 per 10^6 BTU) for the gas, the total energy savings that can be attributed to the insulation would have an annual value of about $2000. A continuous source of 21°C (70°F) water could be used to preheat the residue prior to charging the reactor and also to reduce heat loss from the reactor. Thus, the savings to be obtained from the heated water from the nuclear plant would amount to $2000 to $3000 per year.

Estimated Cost of Methane Generation System

A comprehensive study conducted for the U. S. DOE (Jewell et al., 1976) estimated the lowest cost that might be involved in construction of a complete methane generation system for the size of dairy discussed earlier. This system consisted of the premix tank, pumps and piping, and reactor (including gas handling). For these different designs, the range of total expenditures was $14,500 to $29,500. These estimates would appear to be reasonable according to one commercial firm recently established to build systems at this scale. This firm, Agricultural Engineering Incorporated, has quoted this type of system with an internal combustion engine and a 30KW electricity generator at between $30,000 and $40,000.

The estimated total annual cost of these systems (amortization, operation, and maintenance) varies from $3300 to $7650. These estimates include a minimum amount of insulation, but do not include the benefits from having the 21°C (70°F) water available for reducing construction and reactor heating costs. At the present energy cost of about $10 per 10^6Kcal, the annual return without the 21°C (70°F) water would be about $2400, and with optimum temperature control the gross value of the energy would be nearly double this amount. Since natural gas prices are projected to double in the near future, the energy value with and without the heated water input would be $6000 and $4800. As noted earlier, in some instances comparable manure handling systems that achieve odor control or reduced handling manpower commitments often cost approximately the same as the above costs. In these instances, the cost of the energy is greatly reduced.

Heat Recovery Potential

The value of an unlimited supply of heated water at a minimum of 21°C (70°F) could be significant in operating a biological fermenter at 35°C(95°F). For a 100-cow milking dairy, the energy savings could result in enough to make the operation economically attractive.

There are two general requirements needed to make energy recovery attractive at the scale discussed here:

1. The cost of energy, especially natural gas, must continue to increase in value.
2. The demand for the biogas must be constant and uniform and equal to the production.

The price of natural gas will probably continue to increase in cost; but, matching the demand with the supply is much more difficult. In this case, if it is assumed that the gas can be used to increase the water temperature to a level useful for greenhouse heating, the requirement for a continuing demand may be partially satisfied. Biogas can be compressed and stored for future use or sale.

The energy that could be supplied from the Miller farm residues of 500 x 10^6K cal per year can be translated into the total quantity of water that could be heated to 29°C (85°F) if the starting temperature was 21°C (70°F). Assuming that the transfer efficiency is 100%, the average water flow during a winter day that could be heated to 29°C (85°F) would be equal to 190 cubic meters (50,000 gallons). The total amount of energy and its relation to greenhouse heating needs to be examined.

Recommendations

The recovery of solar energy fixed in presently unused agricultural residues would appear to be representative of several technologies that are ready to be examined for large scale development to assist in development of new, clean, renewable energy sources. However, the lack of full-scale applications on common agricultural operations, such as dairies, is preventing development of costing and feasibility information needed to make key cost effective decisions. The development of a system incorporating nuclear cooling water would assist in demonstrating the feasibility of the operation as well as to illustrate a useful by-product of nuclear power generation.

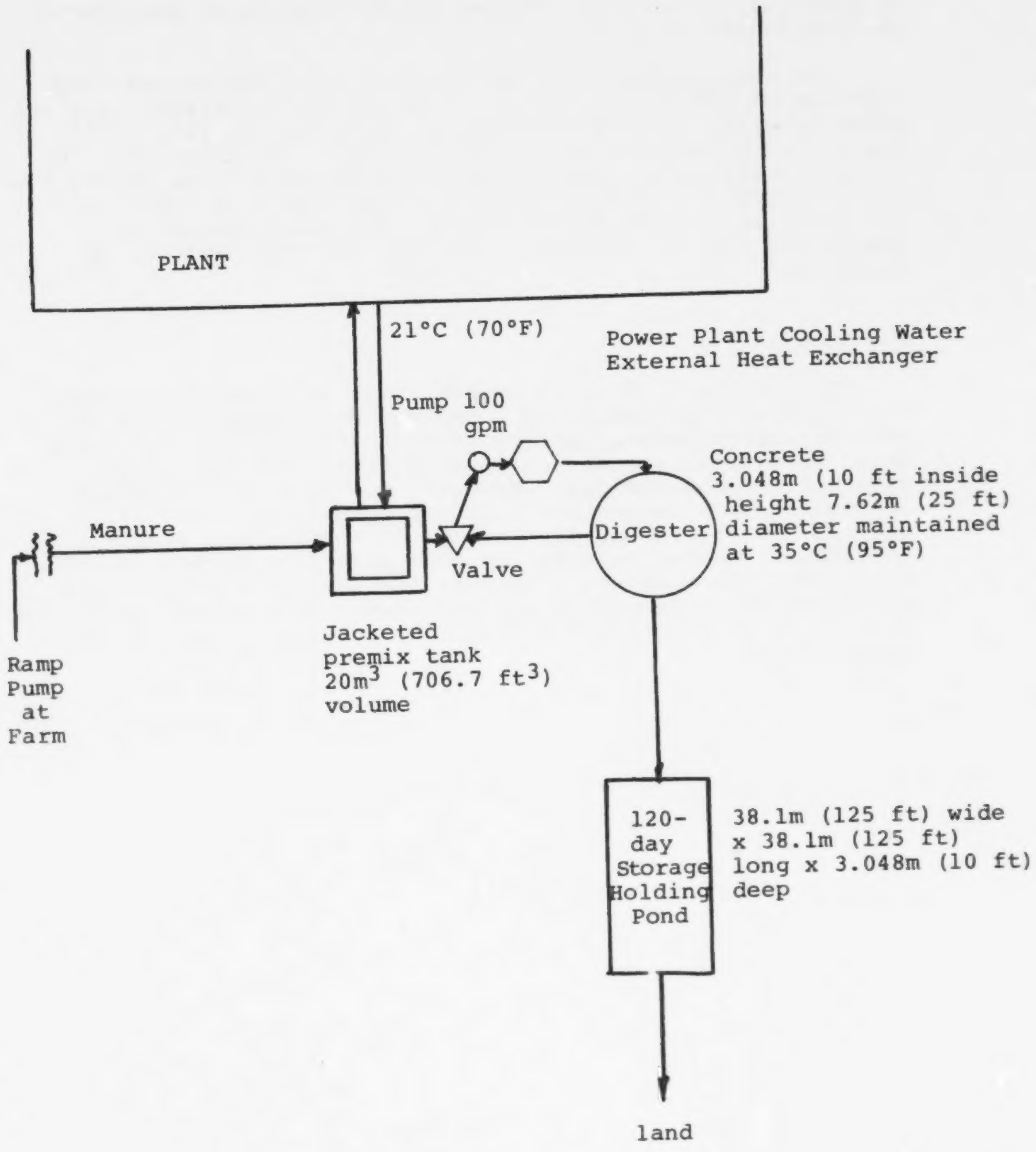
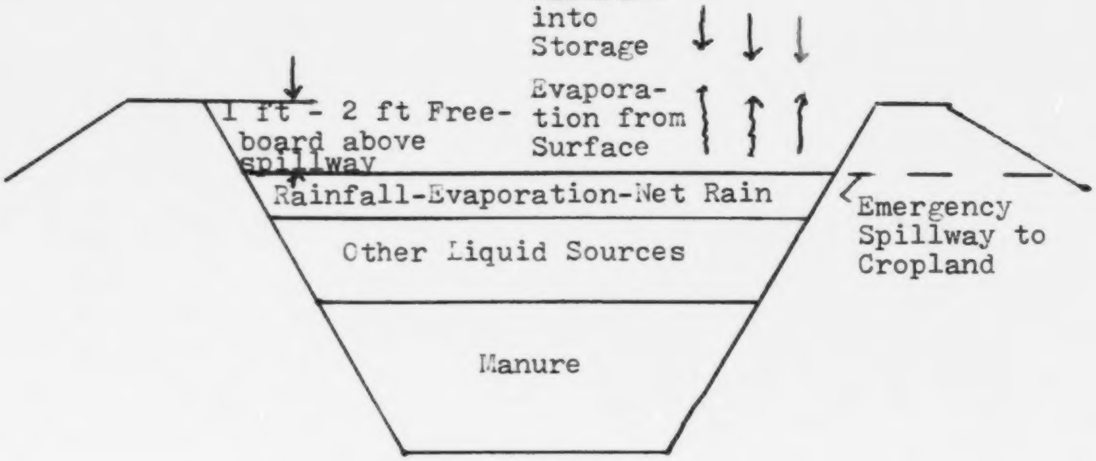
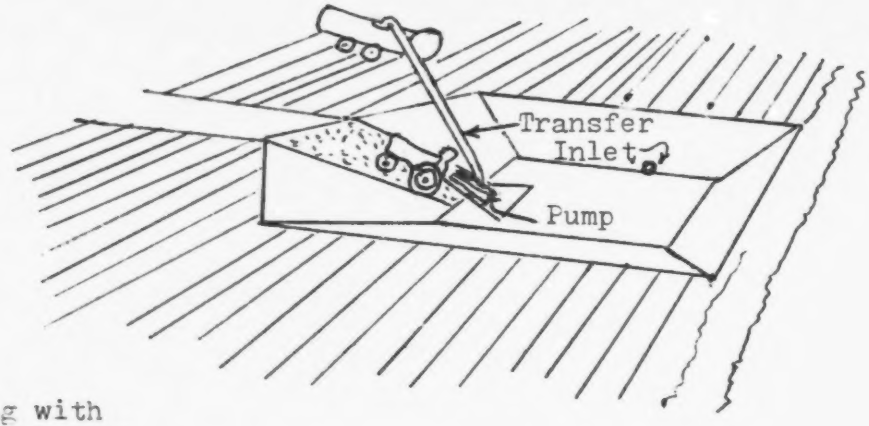

PLANT
21°C (70°F)
Power Plant Cooling Water External Heat Exchanger
Pump 100 gpm
Concrete 3.048m (10 ft inside height 7.62m (25 ft) diameter maintained at 35°C (95°F)
Manure
Digester
Valve
Jacketed premix tank 20m³ (706.7 ft³) volume
Ramp Pump at Farm
120-day Storage Holding Pond
38.1m (125 ft) wide x 38.1m (125 ft) long x 3.048m (10 ft) deep
land

Figure 2. Digester location relative to nuclear plant premix tank and storage holding pond.


Rainfall into Storage
Evaporation from Surface
1 ft - 2 ft Freeboard above spillway
Rainfall-Evaporation-Net Rain
Other Liquid Sources
Manure
Emergency Spillway to Cropland

Liquids stored in holding pond


Transfer Inlet
Pump

Unloading with horizontal pump

Figure 3. Holding pond and unloading pump location.

ANNEX TO APPENDIX B

ANAEROBIC FERMENTER DESIGN FOR A DAIRY FARM OF 200 COWS (TOTAL)

I. Estimation of Agricultural Residues

A. Assumptions

1. Number of cows:
   - 200 total
   - 123 milking
   - 3 bulls
   - 74 replacement

2. Wastes generated
   - Manure: 84 lb/1000-lb cow/day
   - Milking: 33.8 lb/cow/day
   - Bedding: 1.5 lb/replacement cow/day
     - 4 lb/milking cow/day
   - Feed: 1.5 lb/cow/day

3. Combined waste characteristics
   - Total solids (TS): 12%
   - Total volatile solids (VS): 85%

4. Waste is removed on a daily basis and the animals are confined 100% of the time.

5. Average animal weight: 1250 lb

B. Waste Generation

Daily Waste Generation (lb, wet basis)

	123 Milking Cows	74 Replacement Cows	3 Bulls	Total lb.
Manure	13,161	4,086	178	17,425
Milking Center	4,153	--	--	4,153
Bedding	307	110	4	421
Feed Waste	--	--	--	244
		Total Daily Waste (12%TS)		22,243

Full Strength

22,243 lb/day 10 m^3/day (352 ft^3/day) of 12% TS Waste

Diluted to 10% TS

$$10\ m^3/\text{day}\ (352\ ft^3/\text{day}) \times \frac{12}{10} = 12\ m^3/\text{day}\ (422\ ft^3/\text{day})$$

Concentration	Volume of Waste Generation Per Day
12%	10 m^3/day (352 ft^3/day)
10%	12 m^3/day (422 ft^3/day)

II. Fermenter Design

Criteria

Waste flow for 200 cows	12 m^3/day (422 ft^3/day)
Premix tank volume	20 m^3
Pump rate (feeding & recirculation)	.4 m^3/min or 100 gpm
Hydraulic retention time	about 10 days
Temperature	35°C (95°F)
Solids loading rate	8.3 kg/m^3-day (.5 lb/ft^3-day)

Tank Volume

Liquid volume	12 m^3/day x 10 day HRT = 119 m^3
Add about 20% for freeboard	
Tank volume	119 + .2 x 119 = 143 m^3 (5046 ft^3)

Tank Dimensions

A cylindrical tank design, above-ground concrete structure:

Wall thickness	15.24 cm (6 in)
Tank height	3 m (10 ft)
Tank diameter	7.6 m (25 ft)

III. Digester Heating Requirement*

Assume the following conditions apply:

1. Concrete digester surfaced with polyurethane insulation, above-ground construction, of the following dimensions:

Total depth	3.048 m (10 ft)
Liquid depth	2.44 m (8 ft)
Diameter	7.62 m (25 ft)
Concrete wall & floor thickness	15.24 cm (6 in)
Concrete cover thickness	15.24 cm (6 in)
Insulation thickness on walls and cover	10.16 cm (4 in)

---

* Wastewater Engineering, Metcalf and Eddy, Inc., McGraw-Hill Book Company, New York, N.Y., 1972 Ed.

2. Heat Transfer Coefficients

Slurry - 6" concrete - 4" polyurethane-air,
$U = .15$ BTU/hr-ft^2-°F

Slurry - 6" concrete floor - wet soil,
$U = .15$ BTU/hr-ft^2-°F

Gas - 6" concrete wall or cover - 4" polyurethane-air
$U = .05$ BTU/hr-ft^2-°F

3. Temperatures

	Worst Case	Average Case
Digester	35°C (95°F)	35°C (95°F)
Air	-18°C (0°F)	7°C (45°F)
Earth below floor	0°C (32°F)	7°C (45°F)
Feed from barn	1.6°C (35°F)	7°C (45°F)

4. Areas

Wall in contact with slurry
$A = 7.62\text{ m} \times \pi \times 2.44\text{ m} = 58.34\text{ m}^2$ (628 ft^2)

Wall in contact with digester gas
$A = 7.62\text{ m} \times \pi \times .61\text{ m} = 14.6\text{ m}^2$ (157 ft^2)

Floor or Cover
$A = \pi \left(\frac{7.62\text{ m}}{2}\right)^2 = 45.6\text{ m}^2$ (491 ft^2)

Calculations

1. Heat Losses
$Q = A\,(T_2 - T_1)\,U$

Wall in contact with slurry
$Q = 628 \times (95-0) \times .05 = 2983$ BTU/hr, worst case
$Q = 628 \times (95-45) \times .05 = 1570$ BTU/hr, average case

Wall and cover in contact with digester gas
$Q = (157 + 491) \times (95-0) \times .05 = 3078$ BTU/hr worst case
$Q = (157 + 491) \times (95-45) \times .05 = 1620$ BTU/hr average case

Floor
$Q = 491 \times (95-32) \times .15 = 4640$ BTU/hr, worst case
$Q = 491 \times (95-45) \times .15 = 3682$ BTU/hr, average case

2. Heating Requirement for the Feed

Without preheating
Worst case $Q = 22243$ lb/day $\times$ (95-35)°F $\times$ 1 BTU/lb-°F $= 1.33 \times 10^6$ BTU/day (55600 BTU/hr)

Average Case Q = 22243 lb/day x (95-45)°F x
1 BTU/lb-°F = 1.11 x 10^6 BTU/day
(46200 BTU/hr)

After preheating to 18.2°C (65°F) with waste heat
Q = 22243 lb/day (95-65)°F x 1 BTU/lb-°F =
.67 x 10^6 BTU/day (28000 BTU/hr)

- SUMMARY OF HEATING REQUIREMENTS -

Heating Requirements (BTU/hr)

		Walls and cover	Floor	Influent Heating	Total
Without Power					
Plant Waste	Worst Case	6060	4640	55,600	66,330
Heat Usage	Average Case	3190	3680	46,200	53,070
With Power					
Plant Waste	Worst Case	6060	4640	28,000	38,700
Heat Usage	Average Case	3190	3680	28,000	34,870

IV. Digester Gas Yield Estimates

Volatile Solids Destroyed : 32% or 330 kg/day (726 lb/day)
Biogas Produced : 275 m^3/day (9682 ft^3/day)
Methane Produced* : 165 m^3/day (5809 ft^3/day)
Gross Energy Output Rate**: 242,000 BTU/hr

Digester Energy Balance (BTU/hr)

		Gross Production	Digester Heat Losses	Influent Heat Requirement	Net BTU/hr Output
Without Power					
Plant Waste	Worse Case	242,000	10,700	55,600	175,700
Heat Usage	Average Case	242,000	6,870	46,200	188,900
With Power					
Plant Waste	Worse Case	242,000	10,700	28,000	203,300
Heat Usage	Average Case	242,000	6,870	28,000	207,100

---

*Gross methane production calculated from the estimated volatile solids destruction: one liter Methane @ STP = 0.5 l/gVS_D x g volatile solids destroyed.

**The heating value of methane is 995 BTU/ft^3

V. Holding Pond

Criteria

4-month holding capacity

Design

Waste flow = 12 m^3/day (422 ft^3/day) =
1428 m^3/120 days (50460 ft^3/120 days)

4-month waste generation = 12 m^3/day (422 ft^3/day) x
120 days = 1428 m^3 (50640 ft^3)

Average rainfall for Vermont: 45.7 - 121.9 cm/yr
(36 - 48 in/yr)

Overdesign to accommodate precipitation = 50%

Total Pond Volume - 1428 x 1.5 = 2142 m^3 (75,960 ft^3)

Pond Dimensions:
Length 38.1 m (125 ft)
Width 38.1 m (125 ft)
Depth 2.44 m (8 ft) + .070 m (2ft)
freeboard = 3.05 m (10ft)
3 sides sloped 2:1
1 side sloped 3:1

REFERENCES

Jewell, W. J., 1976. "Bioconversion of Agricultural Wastes for Pollution Control and Energy Conservation." U.S. ERDA report TIO - 27614. Available from the NTIS system, U.S. Department of Commerce, Springfield, Virginia 22161. 321 pages.

APPENDIX C

WASTE HEAT UTILIZATION DEMONSTRATION GREENHOUSE DESIGN CONCEPT

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July 1977

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WASTE HEAT UTILIZATION
DEMONSTRATION GREENHOUSE
DESIGN CONCEPT

INTRODUCTION

The concepts designed and described in this report are recommended for developing a demonstration greenhouse complex to use waste heat from the Vermont Yankee Nuclear Power Corporation plant near Vernon, Vermont. The greenhouse complex is part of a total demonstration of waste heat utilization at the site. A companion aquaculture demonstration unit is located at the same site.

Because this concept is for demonstration and testing, four different heating techniques are to be demonstrated. Each of the four greenhouses will be heated either directly or indirectly by warm water 21°C (70°F) from the nuclear power plant.

A recommended crop and cropping pattern is given for each greenhouse. The greenhouse units may be used by universities or other research groups in the area for experimentation and testing of plants and production schemes.

After initial testing of the heating systems, one or more of the designs may be scaled-up to a large commercial production unit. Data collected from the demonstration units will be made available for analysis and used to project large scale operations. The layout of the demonstration units is illustrated in Figure 1.

DESCRIPTION OF DEMONSTRATION COMPLEX

The greenhouse heating demonstration complex is divided into four units. Each unit includes a 7.93 m (26 ft) x 18.3 m (60 ft) greenhouse designed for maximum solar utilization and reduced external heat loss. The greenhouse is designed with a large south facing transparent surface (double layer polyethylene) and an insulated north wall with a high light reflective internal surface. This design provides for increased light levels inside the greenhouse when compared with conventional greenhouse designs. The heat loss is reduced by approximately 60% over conventional designs. (See Figure 1)

Each of the four greenhouses is heated either directly with the warm water from the power plant or indirectly utilizing the warm water to assist a heat pump and to produce methane gas from an anaerobic digester located on a nearby dairy farm.

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is required and more light is required at the plant level.

In this house, one commercial water to air heat exchanger is utilized to assist the plastic heat exchangers. The two exchangers are designed to maintain a minimum of 10°C (50°F) in the greenhouse on the coldest nights. Because of the lower temperature conditions, it is suggested that this house be utilized for cooler temperature potted plants.

Greenhouse No. 4: Methane House

This house is unique in that the total heating is provided by methane gas produced on a nearby dairy farm. The manure from about 200 dairy cows is converted to methane gas in an anaerobic digester located on the farm. The gas is piped to the greenhouse by an underground pipeline.

Gas unit heaters (2) are utilized to provide the total heating of the greenhouse. Sufficient gas will be produced to maintain maximum air temperatures of 18°-21°C (65°-70°F) on a continuous basis. Because of the capability of maintaining the higher temperatures, either roses or cucumbers are suggested as ideal crops for this house.

The warm water from the power plant is utilized indirectly in this instance. The anaerobic digester must be maintained at 32°-35°C (90°-95°F) for maximum gas production. The 21°C(70°F) water from the power plant assists in maintaining the higher temperature in the digester, and more gas is available for outside uses. Without the assistance of the warm power plant water, nearly one-half of the methane gas produced would be required to maintain the 32°-35°C (90°-95°F) in the digester. With the warm water, only 20% of the gas produced will be required by the digester.

In addition to the greenhouses, a head house is required and also space for scientists to collect data from the demonstration units and for visitors to observe the facilities.

DEMONSTRATION GREENHOUSE DESIGNS

Energy Conserving Basic Greenhouse Design

Greenhouses have historically not been designed with energy conservation in mind. The design suggested here incorporates a shape and construction materials to maximize the collection of solar energy while reducing the heat losses from the structure. A descriptive sketch for the greenhouse structure is included with this report. The heating systems to utilize the warmed water discharge from the power plant condenser are all utilized

Greenhouse No. 1: Solar Greenhouse

This greenhouse is equipped to store excess solar energy collected by the greenhouse in gravel storage benches located inside the greenhouse. The heat is recovered from the gravel storage for nighttime heating. In addition to the solar collection and storage, a commercial water to air heat exchanger is utilized. A backup 9.5 kw electric resistance heater is included in the design.

No external solar collectors are utilized as the greenhouse itself acts as the collector. The gravel storage units inside the greenhouse double as the growing benches. An air handling unit was designed to collect excess heat and deliver it to the gravel storage.

Greenhouse No. 2: Heat Pump

The same basic greenhouse design is utilized without the solar storage units. In this house, a water to air heat pump is utilized with a constant source of 21°C (70°F) water supplied by the power plant. The operating coefficient of performance (COP) for the water to air heat pump is approximately 3 compared to 1.75-2.0 for air to air units now commonly used.

In addition to the heat pump, one water to air heat exchanger (commercial unit) will be utilized for base load heating. The heat pump will be utilized as an assist during the coldest operating periods. There is no other backup heating provided for this house, as the heat pump is designed to meet the greenhouse design temperature requirements at the outdoor design temperature of -26°C (-15°F).

Greenhouse No. 3: Rutgers' Design

This design is likely to be the most controversial and may be omitted if regulations prohibit the direct use of the warm water from the cooling system of a nuclear plant. In this house, the floor is constructed of porous concrete and warmed water flows through a gravel bed beneath the floor.

Low temperature, low cost heat exchangers are designed to utilize the warm water directly. Porous pipes are draped with polyethylene sheets the full length of the house in five separate rows. Water flows from the porous pipe down between the plastic sheets and through the porous concrete floor.

The pipes draped with plastic may be raised at night for maximum heat exchange and lowered during the day when less heat within the basic greenhouse design.

For comparison, the heat loss from a conventional greenhouse at the outside design temperature of -26°C (-15°F) and inside design temperature of 18°C (65°F) is calculated to be about 240,000 BTU/hr. The heat loss from the energy conserving design is calculated to be about 100,000 BTU/hr under the same design conditions or about 60% less than the conventional house.

The key to utilization of low temperature heat, such as the power plant discharge or solar energy, is to reduce the heat losses to a reasonable level.

Four different experimental greenhouse heating system designs are suggested for the Vernon plant. Each greenhouse will be the basic nominal 7.93 m (26 ft) x 18.3 m (60 ft) size and incorporate the proper shape and orientation for maximum solar utilization and minimum heat loss from the structure. The standard greenhouse design is illustrated in Figures 2 and 3.

Each greenhouse, except the methane-heated unit, will be partially heated with the 21°C (70°F) discharge water from the power plant condenser discharge. The greenhouse units will utilize water to air heat exchanger units similar to the Trane centrifugal air handler with finned-tube heat exchanger units as used in the Northern States Power demonstration unit.* The units may be purchased from the manufacturer with the specifications provided in the design criteria.

The four greenhouses will incorporate different heating techniques. Greenhouse No. 1 will be equipped to collect, store, and use when needed excess solar energy to partially offset the heating requirements. The design for greenhouse No. 1 is illustrated in Figures 4, 5, and 6. Greenhouse No. 2 will include the use of a warm water-assisted heat pump to provide for a COP of approximately 3. The heat pump will be assisted by one water to air finned-tube heat exchanger. The design for greenhouse No. 2 is illustrated in Figure 7. Greenhouse No. 3 will be referred to as the Rutgers' design and incorporates the technique of underfloor supply of warm water at 21°C (70°F) from the power plant using a porous concrete floor. Low cost, low temperature heat exchangers are designed for additional heating using the condenser water. The greenhouse No. 3 design is illustrated in Figures 9, 10, 11 and 12. The final greenhouse design, greenhouse No. 4 will be partially heated using methane gas generated from an anaerobic digester located on a nearby dairy farm. Greenhouse No. 4 design is illustrated in Figure 8.

---

*Ashley, G. C. and J. S. Hietala. A Sherco Greenhouse: A Demonstration of the Beneficial Use of Waste Heat. Proceedings of the Conference on Waste Heat Management and Utilization, May 9-11, 1977, Miami Beach, Florida.

The greenhouses may be arranged as desired on the Vernon plant property. A suggested layout is given in Figure 1. The warm water supply may be taken directly from the discharge canal for use in greenhouse heating. The exception to this may be the Rutgers' design. If the use of the warmed water directly is prohibited by federal or state regulations, the Rutgers' design may either be eliminated or water supplied from a heat exchanger similar to the one designed to supply warmed water for the aquaculture unit.

A. Heat Loss Estimates for the Basic Greenhouse Design

Design Criteria:
1. 7.93 m (26 ft) x 18.3 m (60 ft)
2. East-west orientation
3. Climatic conditions for southern Vermont
    - a) winter design temperature = -26°C (-15°F)
    - b) greenhouse inside temperature = 10°C (50°F) night
      = 18°C (65°F) day
4. Percent possible sunshine during winter = 40%
5. Insulated north wall "R"* = 16 R units
6. South slope elevation = 38° from horizontal

Heat Loss Estimates:

Floor	9,153 BTU/hr
Thermal Radiation Exchange	30,164 BTU/hr
Cover Loss: Transparent surface + Insulated surface	66,992 BTU/hr
Infiltration Loss (2 air changes/hour)	15,173 BTU/hr
TOTAL	121,484 BTU/hr

If the inside temperature is maintained at 18°C (65°F), the total heat loss estimate is 152,513 BTU/hr. The use of a black cloth curtain drawn over the transparent surfaces has been shown to reduce nighttime heat loss by up to 50%. Using a more conservative factor of 25% reduction, the nighttime heat loss estimate is 91,086 BTU/hr at 10°C (50°F) minimum and 114,384 BTU/hr at 18°C (65°F) minimum interior greenhouse temperature.

B. Solar Greenhouse Design Specifications (Greenhouse No. 1):

Design Criteria:
1. Latitude 43.6°
2. Clear Sky
    - a) insulated surface absorptivity = 0.9
    - b) non-insulated surface absorptivity = 0.21

---

*Thermal Resistance ("R") - The ability of a material or combination of materials to retard or resist the flow of heat.

Total Daily Solar Gain on a Clear Day:

1. Transparent south surface = 1,614,693 BTU
2. Transparent east and west surface = 133,433 BTU
3. North insulated surface = 16,422 BTU
4. South facing insulated surface = 46,676 BTU

TOTAL DAILY SOLAR GAIN 1,811,224 BTU

Heat Storage:

1. Sixty tons of crushed rock may be stored in the benches.
2. Assuming 10°C (50°F) of useful collection and 38°C (100°F) maximum rock temperature, the amount of heat that can be put in the rocks is 1,200,000 BTU.
3. The nighttime heat requirements to maintain the greenhouse at 10°C (50°F) using the black cloth system was 91,086 BTU/hr.
4. Therefore, reclaiming the stored heat from the rock storage would provide approximately 14 hours of heating.
5. It is evident from the calculation of total solar gain on a clear day that on a typical winter day 1,200,000 BTU of solar energy will not be available for storage. The gravel storage may provide heat for 3 to 4 hours of nighttime heating during the design winter period; however, during the spring and fall periods up to 100% of the heating may be offset from the solar collection and storage of excess heat.

Water-to-air Heat Exchangers:

The commercial finned-tube heat exchanger with centrifugal air flow delivery will provide 82,000 BTU/hr if the entering water temperature is 21°C (70°F) and the entering air has a temperature of 10°C (50°F). The water flow rate should be 29 gallons per minute (0.0018 m^3/s) and the air flow rate should be 7000 cfm (3.3 m^3/s).

If the water temperature is 24°C (75°F) with all other parameters the same, the heat exchanger could provide 103,000 BTU/hr.

The suggested exchanger units are available from the Trane Company.

Specifications: Fan (L-12, 7000 cfm)
Coil (Series 16 with 3 rows of tubes)
Motor (3 HP)
Filter and mixing (M-90)

Therefore, given the nighttime maximum heat loss rate of 91,086 BTU/hr to maintain a 10°C (50°F) minimum temperature in the greenhouse, the solar heating with storage and the use of two finned-tube water to air heat exchanger units should ensure the necessary heating requirements. Maintaining 18°C (65°F) in the greenhouse would also be possible; however, long periods of cloudy weather would place the heating at the very limits of the design.

C. Heat Pump Heated Greenhouse (Greenhouse No. 2):

The heat pump will operate at a constant COP of approximately 3, and therefore a commercial heat pump may be selected to supply 160,000 BTU/hr to maintain the greenhouse at a 18°C (65°F) minimum temperature. Carrier Model 2400, or an equivalent heat pump from Westinghouse or General Electric, will be satisfactory.

If the water to air heat exchanger is included in the greenhouse design, the heat pump capacity could be reduced by about 1/2. One heat exchanger unit is recommended to help offset heating cost.

Warm water supplied to the heat pump at 21°C (70°F) would increase the overall winter heating COP from about 1.75 to approximately 3. The electric energy required to heat the greenhouse with such a heat pump is obviously 1/3 that of direct resistance heating and a little less than 2/3 that without the 21°C (70°F) source of water. This heat pump would allow higher operating temperatures in this house for cucumber production.

Annual estimated electrical use for heat pump:

Criteria:
18°C (65°F) (minimum temperature)
114,384 BTU/hr (max. heat loss)
7800 (degree days)
0°C (32°F) (average winter temp.)
21°C (70°F) (average inside temp.)

Annual total electricity required for heating with water-to-air heat pump is:
21,308 Kwhr @ 4¢/Kwhr = $852.00

Direct resistance electric heating would result in 63,925 Kwhr total, and at 4¢/Kwhr the annual cost would be $2,557.00. Therefore, just the annual electrical energy savings by use of the heat pump over direct resistance heating is about $1700.00.

The air to air heat pump would require about 36,500 Kwhr annually at a cost of about $1461.00. Therefore, the value of the warm water from the power plant for greenhouse heating for the 7.93 m (26 ft) x 18.3 m (60 ft) demonstration greenhouse is $609.00 annually.

As a further comparison, the annual cost for heating the greenhouse with #2 fuel oil is estimated to be $1239 if #2 fuel oil costs 50¢/gal. Therefore, the warm water assisted heat pump would save approximately $4000 per year when compared to the use of fuel oil for heating in the No. 2 greenhouse.

The above comparison is given for the situation where all the heating is done by the heat pump. In greenhouse No. 2, the heat pump cost is also offset by the use of the water to air heat exchanger. The estimated total electric cost when using both units is $420 annually.

D. Rutgers' Greenhouse Design (Greenhouse No. 3):

The exchanger consists of a single sheet of plastic film draped over a supporting member and hanging down to the floor on each side (see Figure 11). A trickle irrigation device, twin wall hose, is attached to the supporting member under the film. Warm water supplied by the power plant condenser discharge is pumped from the floor storage into the twin wall hose and flows by gravity between and down inside surfaces of the plastic sheet onto the floor. Since the floor is constructed of porous concrete, no collecting device is needed, and the water returns to the storage area directly under the floor. Tests conducted by Rutgers on this exchanger design indicate an overall heat transfer coefficient of 0.95 BTU/hr-ft^2-°F when there is a 14°C (25°F) temperature difference between the average heat exchanger temperature and inside greenhouse air ambient. The plastic exchangers can be elevated or dropped during the day to avoid shading the crops. Low pump horsepower and energy are required because the storage is just below the floor and the twin wall hose operates at low pressure. Evaporation is limited because the water runs between the layers of film.

Criteria:

1. 5 heat exchanger polyethylene curtains
2. Curtains elevated to 1.22 m (4 ft) maximum
3. Total curtain area = 223 m^2 (2400 ft^2)
4. 1/2 floor area (available for heat exchange)
5. Condenser water at 21°C (70°F) (available in continuous supply)
6. Total water flow = 60 gpm (0.0038 m^3/s)
7. Temperature difference between curtain wall and greenhouse air $\simeq$ delta-T 20°F

Heating supplied by curtain exchanger and floor:

Using the heat transfer coefficient of 1.53 as suggested by Rutgers' design:

Total heat transfer = 73,000 BTU/hr

The Rutgers' design alone will not be adequate to provide a minimum 10°C (50°F) nighttime greenhouse air temperature. Condenser water at 24°C (75°F) would provide this minimum temperature. The addition of one water to air heat exchanger unit will satisfy the heating requirement for the Rutgers' design and a minimum 10°C (50°F). (See Figures 9, 10, 11 and 12.)

E. Methane-Heated Greenhouse (Greenhouse No. 4):

Criteria:

1. Actual digester design data were supplied by Dr. W. J. Jewell*.
2. Estimated daily production for winter conditions for the 200-cow dairy is approximately 200,000 BTU/hr.

Design Requirements:

If 200,000 BTU/hr (methane equivalent) were available on a continuous basis from the dairy farm, the methane-heated greenhouse could be maintained at 18°C (65°F) or higher on a continuous basis with some additional gas available for water heating or other uses at the dairy farm.

The greenhouse should be designed for two, gas-fired, unit heaters to deliver 100,000 BTU/hr each. (See Figure 8.)

F. Summer Cooling (Ventilation):

Criteria:

Summer design temperature
Dry bulb temperature = 32°C (90°F)
Wet bulb temperature = 23°C (73°F)

With these outdoor design conditions and using one air exchange per minute, the inside temperature will rise a maximum delta-t of 4.5°-5.5°C (8°-10°F) over the outside temperature. The inside temperature could reach as high as 43°C (110°F) on the hottest summer days.

The recommended fan capacity for one air exchange per minute for the basic greenhouse design is 374 m^3/min (13,200 ft^3/min)

G. Maximum total water flow from the power plant to the demonstration complex is 200 gpm (0.0126 m^3/s).

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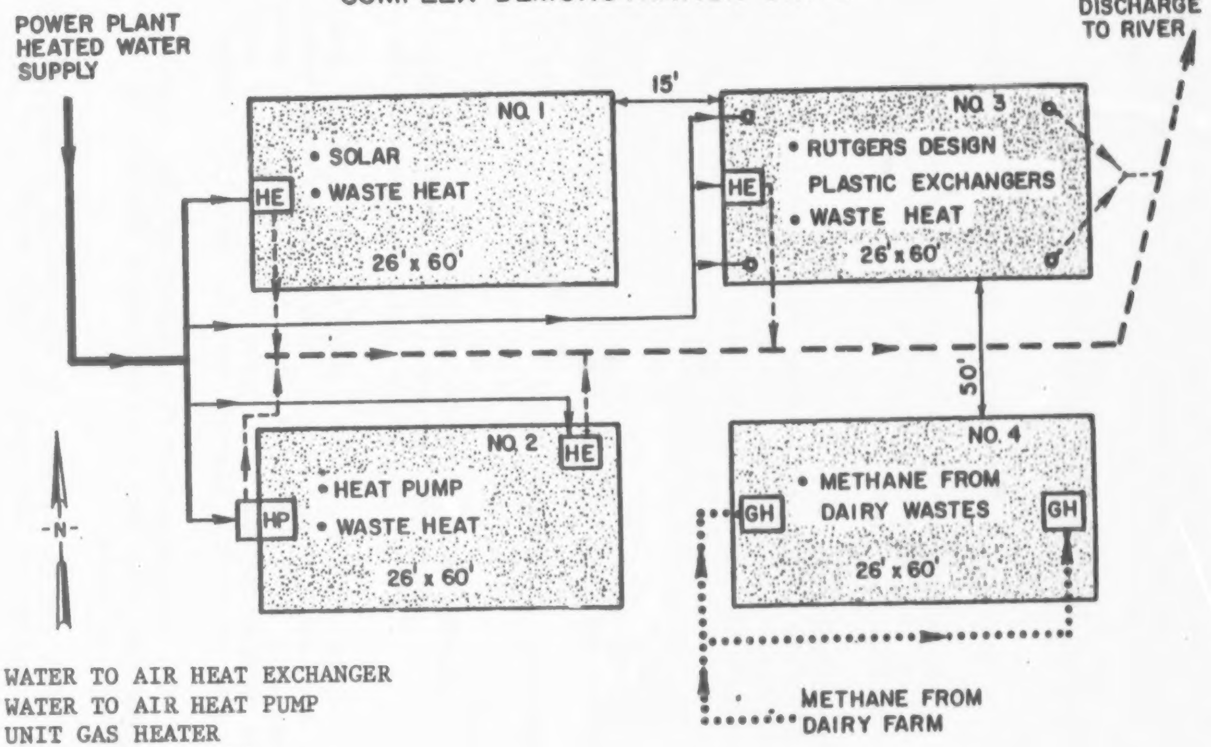
*See Appendix B

GREENHOUSE WASTE HEAT UTILIZATION COMPLEX DEMONSTRATION UNITS


POWER PLANT HEATED WATER SUPPLY
15'
DISCHARGE TO RIVER
NO. 1
• SOLAR
• WASTE HEAT
26' x 60'
HE
NO. 3
• RUTGERS DESIGN PLASTIC EXCHANGERS
• WASTE HEAT
26' x 60'
HE
50'
NO. 2
• HEAT PUMP
• WASTE HEAT
26' x 60'
HP
HE
NO. 4
• METHANE FROM DAIRY WASTES
26' x 60'
GH
GH
-N-
METHANE FROM DAIRY FARM

SYMBOLS:

HE	WATER TO AIR HEAT EXCHANGER
HP	WATER TO AIR HEAT PUMP
GH	UNIT GAS HEATER
———	WARM WATER SUPPLY
----	DISCHARGE BACK TO RIVER
....	METHANE GAS SUPPLY

FIG. I. LAYOUT OF THE GREENHOUSE COMPLEX

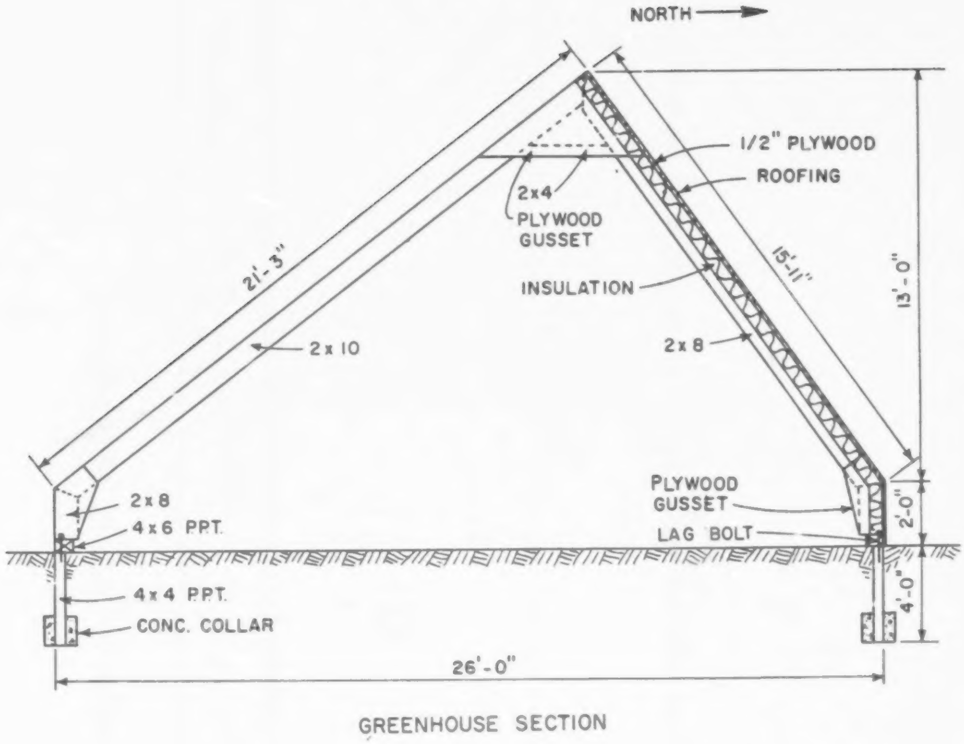

NORTH
1/2" PLYWOOD
ROOFING
2x4
PLYWOOD GUSSET
INSULATION
21'-3"
15'-11"
13'-0"
2x10
2x8
2x8
4x6 P.P.T.
PLYWOOD GUSSET
LAG BOLT
2'-0"
4x4 P.P.T.
CONC. COLLAR
4'-0"
26'-0"
GREENHOUSE SECTION

FIG. 2. END CROSSECTION OF BASIC GREENHOUSE

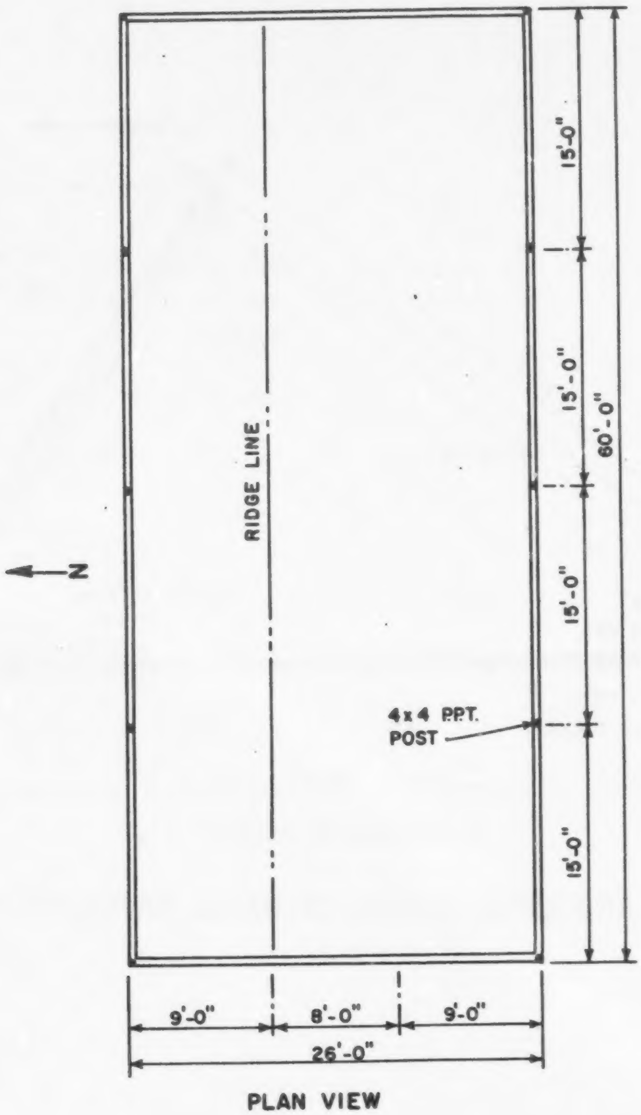
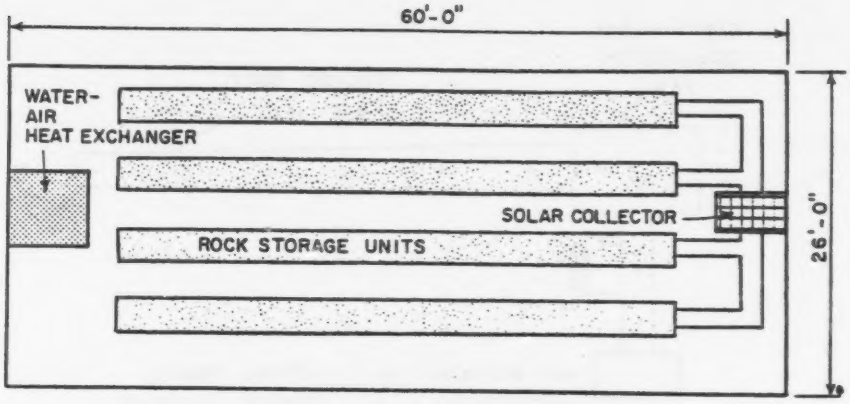
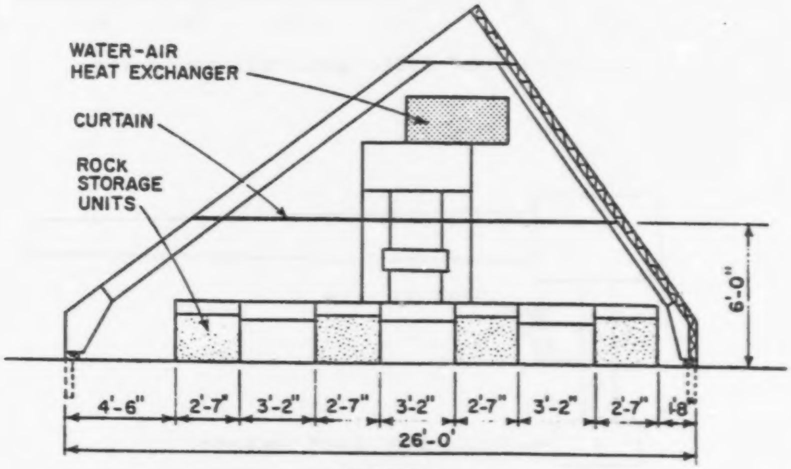

N
RIDGE LINE
15'-0"
15'-0"
15'-0"
15'-0"
60'-0"
4x4 P.P.T.
POST
9'-0"
8'-0"
9'-0"
26'-0"
PLAN VIEW

FIG. 3. PLAN VIEW OF BASIC GREENHOUSE


60'-0"
WATER-AIR HEAT EXCHANGER
SOLAR COLLECTOR
ROCK STORAGE UNITS
26'-0"

PLAN

FIG. 4. PLAN VIEW OF SOLAR HOUSE


WATER-AIR HEAT EXCHANGER
CURTAIN
ROCK STORAGE UNITS
6'-0"
4'-6"
2'-7"
3'-2"
2'-7"
3'-2"
2'-7"
3'-2"
2'-7"
1'-8"
26'-0'

SECTION

SOLAR ASSISTED WITH WATER TO AIR
HEAT EXCHANGER SYSTEM

FIG.5. END CROSSECTION VIEW OF SOLAR HOUSE

COLLECTION — DISTRIBUTION MODES

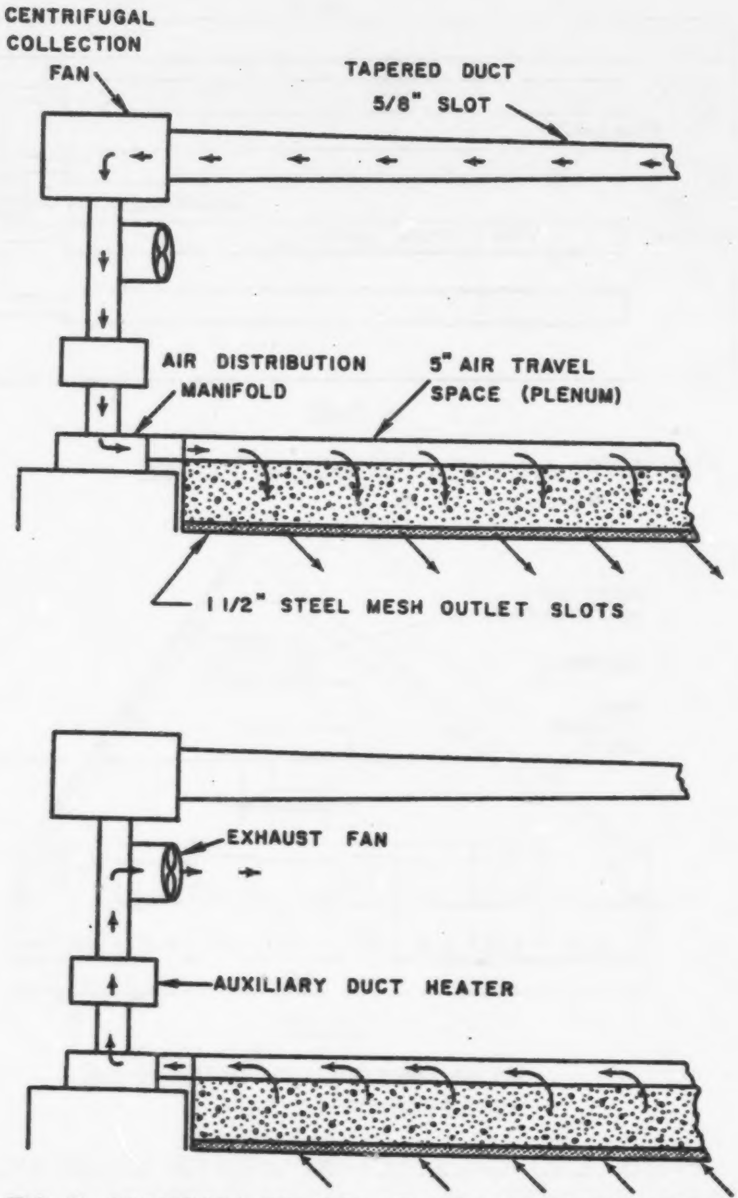
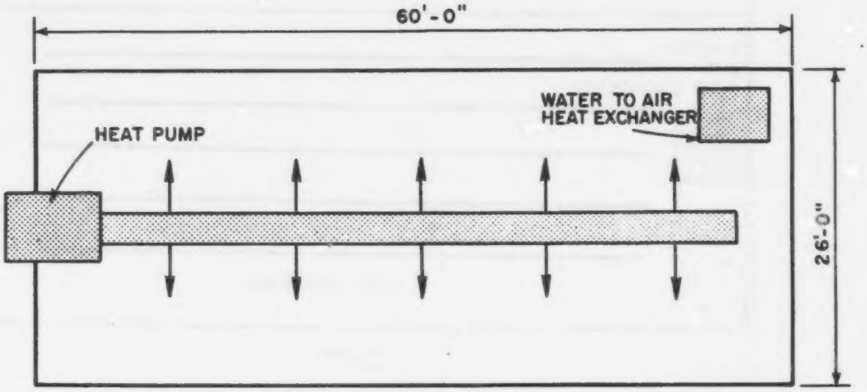
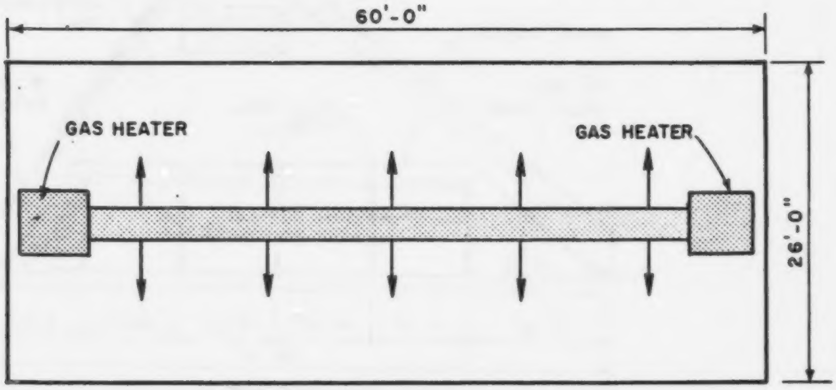

CENTRIFUGAL COLLECTION FAN
TAPERED DUCT 5/8" SLOT
AIR DISTRIBUTION MANIFOLD
5" AIR TRAVEL SPACE (PLENUM)
1 1/2" STEEL MESH OUTLET SLOTS
EXHAUST FAN
AUXILIARY DUCT HEATER

FIG. 6. DIAGRAM OF SOLAR COLLECTION AND STORAGE


60'-0"
WATER TO AIR
HEAT EXCHANGER
HEAT PUMP
26'-0"

WATER TO AIR HEAT PUMP SYSTEM

FIG. 7. HEAT PUMP PLAN VIEW


60'-0"
GAS HEATER
GAS HEATER
26'-0"

METHANE GAS HEATING SYSTEM

FIG. 8. PLAN VIEW OF METHANE UNIT

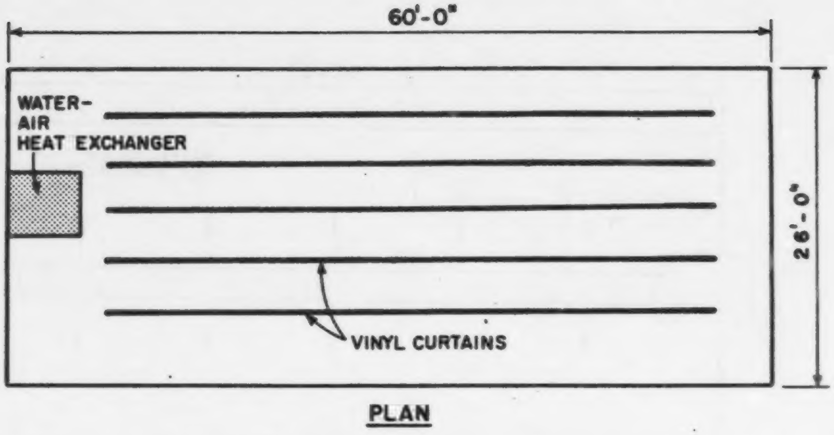
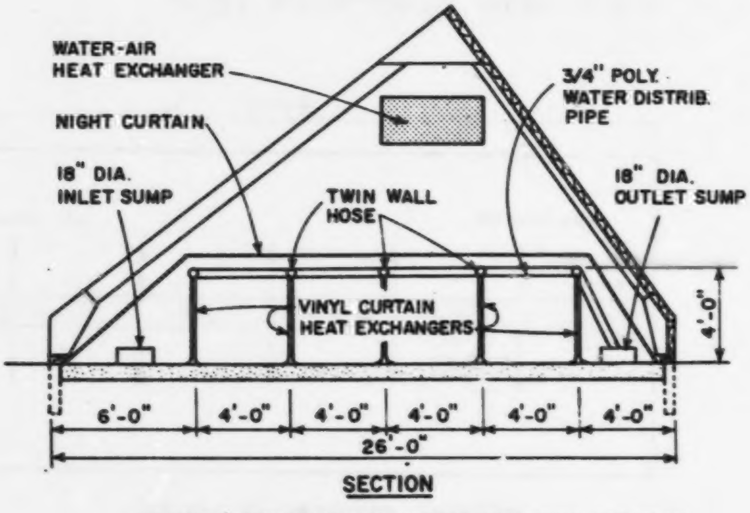

60'-0"
WATER-AIR HEAT EXCHANGER
VINYL CURTAINS
26'-0"
PLAN

FIG. 9. PLAN OF RUTGERS' GREENHOUSE


WATER-AIR HEAT EXCHANGER
NIGHT CURTAIN
18" DIA. INLET SUMP
TWIN WALL HOSE
3/4" POLY. WATER DISTRIB. PIPE
18" DIA. OUTLET SUMP
VINYL CURTAIN HEAT EXCHANGERS
4'-0"
6'-0"
4'-0"
4'-0"
4'-0"
4'-0"
4'-0"
26'-0"
SECTION

RUTGERS' GREENHOUSE FLOOR AND VINYL CURTAIN HEAT EXCHANGER SYSTEM

FIG. 10. END CROSSECTION OF RUTGERS' GREENHOUSE

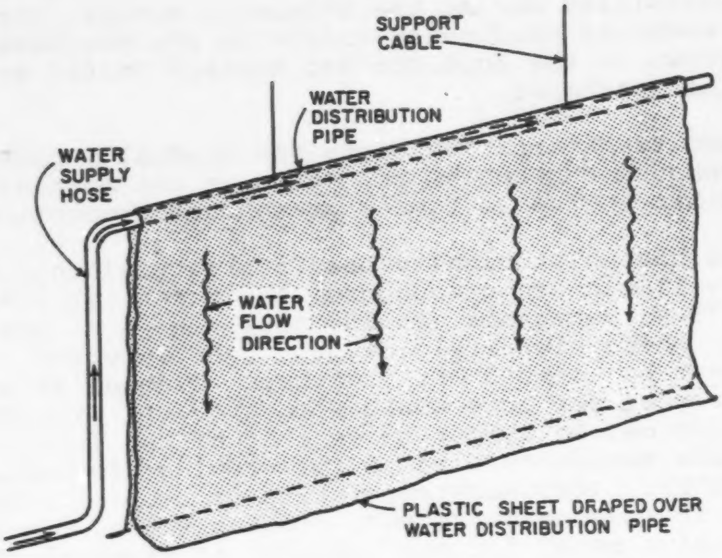

SUPPORT CABLE
WATER DISTRIBUTION PIPE
WATER SUPPLY HOSE
WATER FLOW DIRECTION
PLASTIC SHEET DRAPED OVER WATER DISTRIBUTION PIPE

FIG. 11. PLASTIC VERTICAL CURTAIN HEAT EXCHANGER

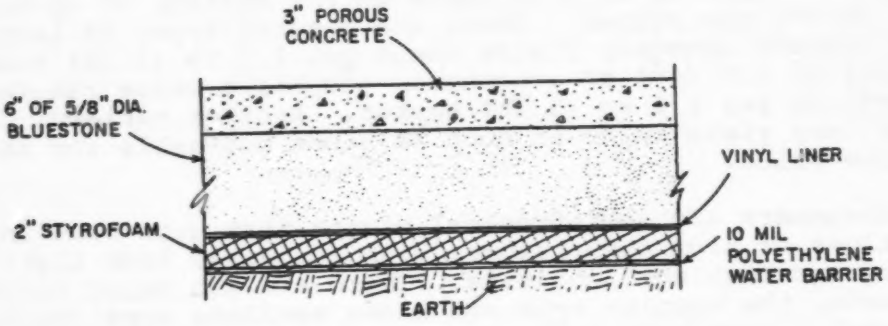

3" POROUS CONCRETE
6" OF 5/8" DIA. BLUESTONE
VINYL LINER
2" STYROFOAM
10 MIL POLYETHYLENE WATER BARRIER
EARTH

FIG. 12. POROUS CONCRETE FLOOR CROSS SECTION

POTENTIAL GREENHOUSE CROPS

Vegetables

Tomatoes, lettuce and cucumbers are the most typical greenhouse vegetable crops. Because of high heating requirements and low light intensities during the midwinter months, very little vegetable greenhouse production exists in the Northeast. Vegetables are grown in the Southern and Western United States and shipped to the Northeast.

Increased transportation costs may gradually cause a shift back to greenhouse vegetable production in the Northeast. New Jersey still has a sizable tomato greenhouse production.

Tomatoes have historically been a high yielding, high value crop. In a well-managed greenhouse, the potential yield of tomatoes is 73-95 megagrams (80-105 tons) per acre per year (two crops). While higher yields have been reported, they are rare and cannot be counted on. A figure of about 82 megagrams (90 tons) per year per acre would seem average. Yields of the spring crop may be almost twice that of the fall crop. The optimum air temperature range for growing of tomatoes is near 21°C (70°F). (Optimum temperature of crops is important, not only because it indicates the best growing range, but also because it can save money for the operator if seasonal changes of temperature are accounted for.) The wholesale price for tomatoes varies from 45¢/lb to 60¢/lb in the Boston market.

Lettuce is a cool weather crop. The optimum temperature range is 13°-15.5°C (55°-60°F), and it will grow well in midwinter. It matures in 8-10 weeks in the spring, or up to 15 weeks during the winter. There are several types of lettuce. Bibbs lettuce commonly yields about one 2.2 kg (5 lb) basket per .929 m^2 (10 ft^2) of greenhouse and has a value ranging from $3.00-$5.00 per 2.2 kg (5 lb) basket. Another variety, Grand Rapids, may yield twice as much as Bibbs but sells for about half the price.

Cucumbers are semi-tropical plants that grow best under conditions of high temperature, high humidity, high light intensity and high soil moisture. There are two major types of cucumbers, the regular type and a new seedless type (English seedless). Both have optimum temperatures in the 27°-29.5°C (80°-85°F) range and thus are usually grown as a late spring crop. The seedless type is rapidly gaining in popularity, but because it cannot be naturally pollenized it must be grown in greenhouses. It thus makes an excellent summer crop for greenhouse production. The seedless variety sells at a much higher price, 30-40¢ per cucumber compared to 15-20¢ per cucumber for the regular type. The yield per acre per crop is approximately 96,000-103,200 cucumbers. If grown the year around, one could get about 5 crops for a maximum of 234,389 kg (518,000 lb) of cucumbers per acre.

Other vegetables, such as radishes [optimum temperature 15.5°-21°C (60°-70°F)] could also be grown. Their value on the market is much less, and thus radishes are not normally included in production schemes.

Cropping Patterns

Using the crop information and incorporating growing time, temperature, planting procedures, etc., several crop patterns are possible. All of the following can be found in greenhouses in the Northeast although some may be on a very small scale.

Plan	Fall Early (Winter)	Mid-Winter	Spring	Summer
1	Tomato		Tomato	
2	Tomato		Cucumber	
3	Tomato	Lettuce	Cucumber	
4	Lettuce		Tomato	
5	Lettuce	Lettuce	Tomato	
6	Lettuce	Lettuce	Cucumber	
7	Lettuce	Lettuce	Lettuce	
8	Tomato	Lettuce	Tomato	Seedless Cucumber
9	Cucumber Crop Year Around (more than 5 crops)			
10	Tomato	Lettuce	Tomato	

Plan #1: a) Tomatoes: Seed sown Oct. 25 to Nov. 10. Plants set in houses about Jan. 10, vines removed July 1 to Aug. 1.
b) Tomatoes: seed sown June 15 to July 1. Plants set in houses Aug. 1-15, vines removed Dec. 15 to Jan. 1.

Plan #2: Similar to #1

Plan #3: a) Tomatoes: seed sown July 1-15. Plants set in houses Aug. 15-30, vines removed Dec. 15-31.
b) Lettuce: seed sown Nov. 15-30. Plants set in houses Dec. 15-31. Crop harvested March 15-31.
x) Cucumbers: seed sown Feb. 1-15. Plants set in houses April 1-15, vines removed July 1-15.

Plan #4: a) Lettuce: anytime early fall or mid-winter.
b) Tomatoes

Plan #5: a) Lettuce: one early fall planting, seed sown Aug. to Sept., transplanted in late Sept., harvested late Oct. and early Nov.

b) Second crop seeded late Oct., transplanted in mid-Nov., harvested in Feb.

Plan #6: Similar to #5.

Plan #7: Same as #5, only continue with lettuce.

Plan #8: Same as #3, except substitute tomatoes for late spring crop, and grow seedless cucumbers in summer months.

Plan#9: Self-explanatory.

Plan #10: Derived from Plan #8.

Table 1. Approximate Yields

Plan		Yield
1	Tomato-Tomato	90 tons/acre*
2	Tomato	30 tons/acre*
	Cucumber	8600 doz/acre
3	Tomato	30 tons/acre*
	Lettuce	43,560 lb/acre
	Cucumber	8600 doz/acre
4	Lettuce	43,560 lb/acre
	Tomato	60 tons/acre
5	Lettuce	
	Lettuce	2 x 43,560 lb/acre
	Tomato	60 tons/acre
6	Lettuce	
	Lettuce	2 x 43,560 lb/acre
	Cucumber	8600 doz/acre
7	Lettuce	
	Lettuce	
	Lettuce	3 x 43,560 lb/acre
8	Tomato	30 tons/acre
	Lettuce	43,560 lb/acre
	Tomato	60 tons/acre
	Cucumber	8600 doz/acre
9	Cucumber (all year)	518,000 lb/acre
10	Tomato	30 tons/acre
	Lettuce	43,560 lb/acre
	Tomato	60 tons/acre

---

* It was assumed spring tomato production to be approximately two times that in the fall. 1.0 kg = .0011 short U.S. ton or 2.205 lb.

Other Crops

The more common and more profitable use of greenhouses in the Northeast in recent years has been for floriculture production. Greenhouse temperatures in the range of 13°-15.5°C (55°-60°F) are acceptable for growing roses, tree seedlings, snapdragons, and many varieties of potted plants. Roses grow best in a temperature above 18°C (65°F) but will tolerate periods of temperatures below 10°C (50°F).

Under the present market structure, the profit from the production of flowers will generally be greater than vegetable production and involves less fluctuation in market price.

Background on Commercial Flower Production

Managers of greenhouse floriculture firms generally produce crops from propagation material (plant cuttings, bulbs, started plants, seeds) provided by a relatively small number of national propagation firms. These firms have elaborate propagation, production and distribution operations which enable them to provide growers with disease-free, pest-free propagation material of high quality at the precise time the grower requires it for his production program.

A commercial greenhouse flower grower manages production to ensure maximum use of greenhouse production area each week of the year. In order to effectively serve his markets, a grower of cut flowers develops tightly scheduled crop rotations which enable him to place a specified amount of cut flowers in the market each week. He supplements this production with additional units of crops for major holiday and special occasion markets, e.g., Easter, Christmas, peak wedding months, etc.

Roses, orchids and carnations, all major cut flower corps, are produced on 4-year, 3-6 year and 1-2 year rotations, respectively. A rose grower orders planting stock to be grown for his purposes often a year or more before it is required for benching. The cost of plants and of the labor and other activity involved in planting represents a significant cost input. Most growers capitalize their rose plants and depreciate the investment over the 4-year production period. Orchids represent an even greater investment per plant with 3-6 year rotations being common. Carnation crops are managed in a similar way but generally only over a 1-2 year period. Loss of these crops as a result of interruption of heat would result in loss of a substantial portion of a multi-year investment.

Chrysanthemums, snapdragons, asters, bulb crops and most other cut flower crops are produced on 3-4 month rotations planned to provide weekly marketings on a year-round basis. While there is considerably less investment in planting stock for these crops than for roses, orchids and carnations, there is nonetheless a considerable financial investment. Producers of potted crops and garden bedding plants are similarly dependent upon national suppliers for the seeds, cuttings, bulbs and stock plants with which crops are initiated. Potted crops grown include poinsettias, Easter lilies, tulips, daffodils, hyacinths, azaleas, chrysanthemums, hydrangeas and geraniums.

In the case of some greenhouse crops and especially geraniums, poinsettias, and foliage plants, stock plants are grown by producers for the purpose of providing propagation material from which to initiate final crops for market. For example, potted geraniums produced for spring sales are often propagated from cuttings taken from large stock plants started the previous summer and grown through the fall, winter and early spring. Growers essentially store cuttings of the large stock plants so as to have considerable amounts of cuttings available from which to start the major finished crops. A heating interruption that resulted in the loss of these stock plants would essentially eliminate the opportunity for the grower as well as the other growers whom he supplies to have a source of propagation material for these crops.

SUGGESTED PLANTINGS FOR DEMONSTRATION GREENHOUSES
(Varieties and Schedule)

A. Greenhouse No. 1

1. Set plants Aug. 1-15 - Tomato (Vendor or Michiana 140)
2. Remove vines Dec. 15-31
3. Set plants Dec. 15-31 - Lettuce (Bibbs)
4. Harvest March 15-31
6. Set plants April 1-15 - Tomato (Vendor or Michiana 140)
8. Vines removed July 1-15

B. Greenhouse No. 2

Cucumber crop year around
5 crops total (English Seedless)

C. Greenhouse No. 3

Potted plants, cut flowers
Variety of species planted to meet special holidays
Chrysanthemums (new variety - cool temperature)
Snapdragons (grow well at low temperature)
Asters
Poinsettias
Easter lilies
Geraniums
Hydrangeas
Best bet: Snapdragons [can grow at 10°-13°C (50°-55°F)]
One bench of chrysanthemums of the new variety that grow well at low temperatures (ask plant salesman for new variety)

D. Greenhouse No. 4

The color and variety of roses grown depends on the needs of the sales outlets in the area. The following may be grown:

1. Red (most standard color)
    - a) Forever Yours (most common variety)
    - b) American Beauty (second most common)
    - c) Samanathe (new variety - very good so far)
2. White - White Butterfly (most common)
3. Yellow
    - a) Golden Fantasy
    - b) Golden Wave
4. Pink
    - a) Sonia (grows well)

Sweetheart varieties suggested are:
1. Red (Mary Devor)
2. Pink (Bridal Pink or Carol Amling)
3. Yellow (Golden Garnett)

Suggested best combination:
2/3 of house - Red (Forever Yours)
1/3 of house - Pink Sweetheart (Bridal Pink)

A period of 6-8 weeks elapses between cuttings from same stem so a limited number of varieties can be effectively grown in one 7.93 m (26 ft) x 18.3 m (60 ft) house.

DEMONSTRATION GREENHOUSES
COST ESTIMATES*
(Initial Costs)

The cost of materials and labor for construction of the basic greenhouse is broken down as follows:

1.	Materials: 7.93 m (26 ft) x 18.3 m (60 ft) unit	$2475.00
2.	Erection (labor)	1050.00
3.	Ventilation Fan (13,000 cfm)	425.00
4.	Basic wiring, lighting, etc.	275.00
5.	Black cloth for night heat retention	175.00
6.	Miscellaneous	125.00
	TOTAL	$4525.00

The individual demonstration greenhouse costs are estimated as follows:

---

* All costs are based on 1977 dollars

A. Greenhouse No. 1 (Solar, waste heat)

1.	Basic greenhouse	$ 4,525.00
2.	Rock storage units 61 m (200 ft)	600.00
3.	Rocks (No. 3 crusher run)	325.00
4.	Air handling duct	275.00
5.	Collection fan	225.00
6.	Discharge fan	225.00
7.	Controls	175.00
8.	Centrifugal water to air heat exchangers (2) (Trane Co.)	3,200.00
9.	Pipe and plumbing for Trane units	625.00
10.	Miscellaneous	500.00
	TOTAL	$10,675.00

B. Greenhouse No. 2 (Heat Pump)

1.	Basic greenhouse unit	$ 4,525.00
2.	Heat pump (Carrier Model 2400 or equivalent) 200,000 BTU/hr rating	3,750.00
3.	Plumbing and controls for heat pump (including wiring)	375.00
4.	Polytube air distribution	65.00
5.	Centrifugal water to air heat exchanger (Trane Co.)	1,600.00
6.	Plumbing and controls for Trane unit	350.00
7.	Miscellaneous	500.00
	TOTAL	$11,165.00

C. Greenhouse No. 3 (Rutgers' Design)

1.	Basic greenhouse unit	$ 4,525.00
2.	Porous concrete floor	1,500.00
3.	Vinyl liner	550.00
4.	Polyethylene curtain heat exchangers (5)	850.00
5.	Centrifugal water to air heat exchanger (Trane Co.)	1,600.00
6.	Plumbing and drains for under floor water reservoir	850.00
7.	Plumbing and controls for Trane unit	350.00
8.	Miscellaneous	500.00
	TOTAL	$10,725.00

D. Greenhouse No. 4 (Methane)

1.	Basic greenhouse unit	$ 4,525.00
2.	Unit gas heaters (2) (100,000 BTU/hr each)	1,650.00
3.	Wiring and controls	325.00
4.	Plumbing for gas supply at greenhouse only	225.00
5.	Polytube air distribution	130.00
6.	Miscellaneous	500.00
	TOTAL	$ 7,355.00

E.	Headhouse for storage and handling and office space (Rough estimate)	$18,000.00
F.	Greenhouse Operational Equipment	
	1. Tools	600.00
	2. Watering systems	1,200.00
	3. Soil	550.00
	4. Miscellaneous	1,000.00
		$ 3,350.00

Greenhouse No. 1	$10,675.00
Greenhouse No. 2	11,165.00
Greenhouse No. 3	10,725.00
Greenhouse No. 4	7,355.00
Headhouse	18,000.00
Operational equipment	3,350.00
TOTAL INITIAL INVESTMENT	$61,270.00

COST ESTIMATES

(Annual Operating)

A.	Labor	
	1. Horticulturist Salary and Fringe Benefits	$ 9,600.00
	2. Part-time maintenance	4,600.00
	3. Part-time workers	2,000.00
	TOTAL	$16,200.00
B.	Fertilizers, pesticides	375.00
C.	Vehicle (depreciation & operating)	1,800.00
D.	Electricity	1,250.00
E.	Plants, seeds, etc.	250.00
F.	Miscellaneous	500.00
	TOTAL	$20,375.00

ESTIMATED PRODUCTION INCOME

(Annual)

1.	Greenhouse No. 1	
	a) Tomatoes (full crop) 6lb/plant, 390 plants/house @ 50¢/lb	$ 1170.00
	b) Lettuce (winter)	546.00
	c) Tomatoes (spring crop) 14 lb/plant, 390 plants/house @ 50¢/lb	2730.00
		$ 4446.00
2.	Greenhouse No. 2	
	Cucumbers (English Seedless) 5 crops (3438 cucumbers/crop @ 40¢/cucumber	$ 6876.00
3.	Greenhouse No. 3	
	Snapdragons 1 bench of Chrysanthemums	$ 6380.00
4.	Greenhouse No. 4	
	2/3 Red Roses (Forever Yours) 1/3 Sweetheart Roses (Bridal Pink)	$ 7962.00
	TOTAL GROSS INCOME	$ 25,664.00

GREENHOUSE HEATING SYSTEMS AND HEAT LOSS CALCULATION TECHNIQUE

Heating System Efficiencies

The following is a list of efficiencies for various systems, as given by the American Society of Heating, Refrigerating, and Air Conditioning Engineers Guide (the ASHRAE Guide).

Table 2. Heating System Efficiencies

Type of Unit	Efficiency
Gas (designed unit)	70-80%
Gas (conversion unit)	60-80%
Oil (designed unit)	65-80%
Oil (conversion unit)	60-80%
Bituminous coal (hand fired, with controls)	50-65%
Bituminous coal (hand fired, without controls)	40-60%
Bituminous coal (stoker fired)	50-70%
Anthracite coal (hand fired, with controls)	50-65%
Anthracite coal (stoker fired)	60-80%
Coke (hand fired, with controls)	60-80%
Coke (hand fired, without controls)	50-65%
Electric	90-99%

These figures are for efficiency of utilization, not furnace (or conversion fuel) efficiency. These figures reflect the heat actually delivered to the structure after accounting for such things as heating effects from the chimney, flue losses, etc.

It can be seen that due to the large number of overlapping ranges, and from the vast number of alternatives known to exist within each general area, that efficiency alone is not the sole basis for selecting a system.

Here a system will be chosen by accounting for the capital cost and then calculating operating costs based on efficiencies, fuel choice, etc; however, this will be done for specific cases, with specific problems and equipment in mind.

Unit Heaters vs. Central Heating

It is generally agreed that for small greenhouses [under 1858 m^2 (20,000 ft^2)] hot air unit heaters are the most economical to operate. The biggest problem with hot air heaters is delivering the heated air uniformly over an area without causing undue drafts. Polytubing and various venting systems have largely taken care of this problem.

For heating larger areas, (on the order of more than an acre under glass) unit heaters cost about the same as using a central system. Thus, even large-scale operations are often heated with unit heaters. However, operating one large central system requires less continual maintenance than does a system of unit heaters. Since costs may still be similar, the choice of heating system is more a matter of individual preference for each greenhouse operator.

There are advantages to starting with glass if the capital is available. This is because: (1) the plastic will probably have to be replaced every year at a cost of about 21¢/ft^2; (2) the plastic houses cannot be depreciated as glass houses can because they are often not considered "permanent" structures; and (3) plastic, in general, will not transmit light as well as glass and may have more condensation problems. (Plastic houses may, on the other hand, have lower heating costs as their overall heat loss coefficient is lower: 0.8 BTU/ft^{2}hr°F as compared to 1-1.2 BTU/ft^{2}hr°F for glass.)

Central Systems

If a central system is to be installed, there are many options open as to: (1) hot water vs. steam heating; (2) piping arrangements; (3) pumping arrangements, etc.

It is generally thought that for small greenhouses, the hot water systems are the most practical. When the size exceeds 1400-1858 m^2 (15,000-20,000 ft^2) of glass, it is probably better to use a steam system.

Hot water will require larger heating pipes than steam. Due to resistance effects, box coil piping is best for hot water, while trombone (continuous) coils are best for steam. (The normal steam setup is 2/3 side coils and 1/3 overhead coils evenly distributed. Note that steam systems can sometimes be utilized for providing soil sterilization, giving this added benefit. There is an increasing use of finned piping for both cases (since one length of finned piping may be equivalent to using four or more plain pipe lengths).

Modern hot water systems under pressure can allow water temperatures close to that of steam but at a higher capital cost than the normal hot water system. This will allow its acceptance for larger heating ranges. In either hot water or steam systems, those operating on a gravity flow basis are no longer considered as economical relative to forced flow systems.

As far as the boilers themselves, normally a water-tube boiler is more efficient than a fire-tube boiler. As far as choice of fuels for the boiler, it will depend on the individual location and specific heating needs.

Use of Electric Heaters

The high cost of electric heating almost disqualifies it as a major source of full-time heating. However, it is a viable alternative when: (1) low cost electric power is available; (2) in very isolated locations where transporting fuels is a problem; (3) very intermittent use is required; (4) supplementary heating is needed, therby allowing a small heating system to be adequate for a majority of the time in lieu of a large system with a great deal of excess capacity; or (5) a heat pump is utilized with an assist from solar or low-grade waste heat discharged from a power generating station.

Fuel Prices

Table 3 is an approximate listing of various fuel costs in the Northeast area and for the most part assumes bulk purchases (as of August 1977).

Table 3. Cost of Common Fuels

Regular Gas	63.9¢/gal*
Premium Gas	69.9¢/gal
Unleaded Gas	66.9¢/gal
Kerosene	48.6¢/gal
#2 Heating Oil	48¢/gal
#4 Fuel Oil	41.5¢/gal
#6 Fuel Oil	39.5¢/gal
Diesel	54.3¢/gal
LP Gas	\$20.50/100 lb
Natural Gas	
Residential	23¢/100 ft^3
Commercial	20-22¢/100ft^3
Wholesale	11-12¢/100 ft^3
**Coal	\$35-\$45/ton

* 1.0 gal = 3.76 l; 1 lb = .4526 kg; 1.0 m ton = 1.023 U.S. ton

** The coal figure is for bituminous low sulfur coal, delivered by truck

Estimating Heat Loss

It is useful to be able to calculate the approximate heat losses from a greenhouse, and if done correctly, the resulting estimate may be used to accurately size the heating system and estimate fuel costs.

The following method is suggested to estimate heat loss when designing a heating unit. Letting "M" equal the heat loss in BTU/hr;

$$M = (h_c)\ (A)\ (t_d - t_o) \qquad (1)$$

Criteria:

h_c = overall heat transfer coefficient - BTU/ft^2 hr °F
1.15-1.2 for glass
1.00-1.2 for polyethylene
.8 for double filmed polyethylene

A = surface area for each type of cover, ft^2

t_d = indoor design temperature [normally 15°C (60°F)], °F

to = outdoor design temperature [-(23.5-29)°C (-(10-20)°F)] for most areas within the Northeast], °F

After calculating the heat loss, add an additional 10% to the final total to account for infiltration. This procedure should give a satisfactory estimate although there are more exact means. The heat loss figure obtained at this point is the maximum loss that needs to be designed for, and it is this figure that is used to select a furnace unit. The design temperatures are the key to this equation. The outdoor design temperature is the mean of extremes based on weather data. The indoor design temperature is based on normal greenhouse practice and depends on the plants grown.

Estimating Fuel Costs for Seasonal Operation

Once the heating requirements have been determined, the next step is to estimate the seasonal costs of heating. The method used here is ASHRAE's "Calculated Heat Loss Method." Basically, it takes the design heat loss and adjusts it according to local conditions. In other words, one would not expect to operate at the extreme design point all winter long.

The first step in this method, then, is to take the design heat loss, "M", and place it into the following equation to obtain an average heating requirement for the period under consideration.

$$X = \frac{M(t-t_a)}{(t_d-t_o)} \qquad (2)$$

Criteria:

t = average inside temperature grower wants to maintain during the heating period (°F)

t_a = average outside temperature during estimate period (with October 1 - May 1 heating season). (ASHRAE Guide lists these by city.)

t_d = inside design temperature, 15°C (60°F)

t_o = outside design temperature, -23.5°C (-10°F)

The quantity of fuel used is equal to F and

$$F = \frac{XN}{EC} \qquad (3)$$

Criteria:

X = average heating requirement for the period under consideration
N = number of heating hours in the estimate period (i.e., October 1 - May 1, figuring 212 days x 18 hours/day for heating needed = 3816 hours).
E = efficiency of utilization of the fuel over the period expressed as a decimal (Table 1).
C = heating value of one unit of fuel or energy (See Table 4).

Then, knowing the price of fuel (or using a value in Table 3), multiply the price times F to obtain the approximate cost of fuel in a given year.

Table 4

Values of C = heating value of one unit of fuel or energy

Fuel	Average Heating Value BTU/gal	BTU/lb	Average Weight lb/gallon
Gasoline	123,769	20,125	6.15
Kerosene	130,637	19,155	6.82
#2 Fuel oil	139,400	19,557	7.128
#4 fuel oil	145,600	19,178	7.592
#5 light fuel oil	148,400	18,994	7.813
#5 heavy fuel oil	150,700	18,873	7.985
#6 fuel oil	153,600	18,616	8.251
Butane	98,832	20,420	4.84
Propane	87,959	20,745	4.24
Coal (bituminous)		12,500	
Methane (Natural gas)	1000 BTU/ft^3	1000 BTU/ft^3	

From 1972 ASHRAE Handbook of Fundamentals, p. 234, 239.

APPENDIX D

ORNAMENTAL HORTICULTURE USING BIOGAS BOOSTED GREENHOUSES

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APPENDIX D

SIMULATION OF GREENHOUSE OPERATION

The following program analyzes the profits from the growth of roses in Cornell-designed greenhouse No. 4. This greenhouse is heated with biogas heaters using fuel from anaerobic digesters which are constructed adjacent to the greenhouses.

Marketing information for the program was provided by the Montgomery Rose Company of Hadley, Massachusetts. Costs for operating an anaerobic digester were obtained from the report "Process Feasibility Study Flow: The Anaerobic Digestion of Dairy Cow Manure at the State Reformatory on a farm in Monroe, Washington". This was prepared by the ECOTOPE Group, Research Consultants, P.O. Box 559, Seattle, Washington, 98105. Other economic data were obtained from the "Waste Heat Utilization Demonstration Greenhouse Design Concept" (see Appendix C).

A detailed flowchart of the model follows. It should be noted, however, that some parameters are not included in the model and must be calculated separately. The initial costs of site work, utilities, etc. are not included in the simulation. Also, profits from the sale of concentrated fertilizer produced by the biogas converter have not been calculated.

The program is written in FORTRAN; it has been designed to be executed in an interactive mode on the Honeywell Time Sharing system available at the University of Vermont. Results from the program are summarized in the following table.

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TABLE 1

SUMMARY OF PROGRAM OUTPUT

Type	No. of Green-houses	Initial Cost of Green house	Initial Cost of Digester	Annual Operation Cost of Greenhouse	Annual Operation Cost of * Digester	Income From Sale of Roses	Income From Sale of Biogas	Total Income	Total Cost
Heated	2	50,770	71,040	26,131	23,630	25,920	3221	29,141	50,446
Summer	2								
Heated	3	50,770	71,040	27,789	23,630	31,680	2804	34,484	52,170
Summer	1								
Heated	4	50,770	71,040	29,446	23,630	37,440	2666	40,106	54,140
Summer	0								

Summer greenhouse will only operate 20 weeks out of the year. The heated greenhouse will operate year-around. Other income may be derived from the sale of excess methane which may amount to 860,000 cf per year.

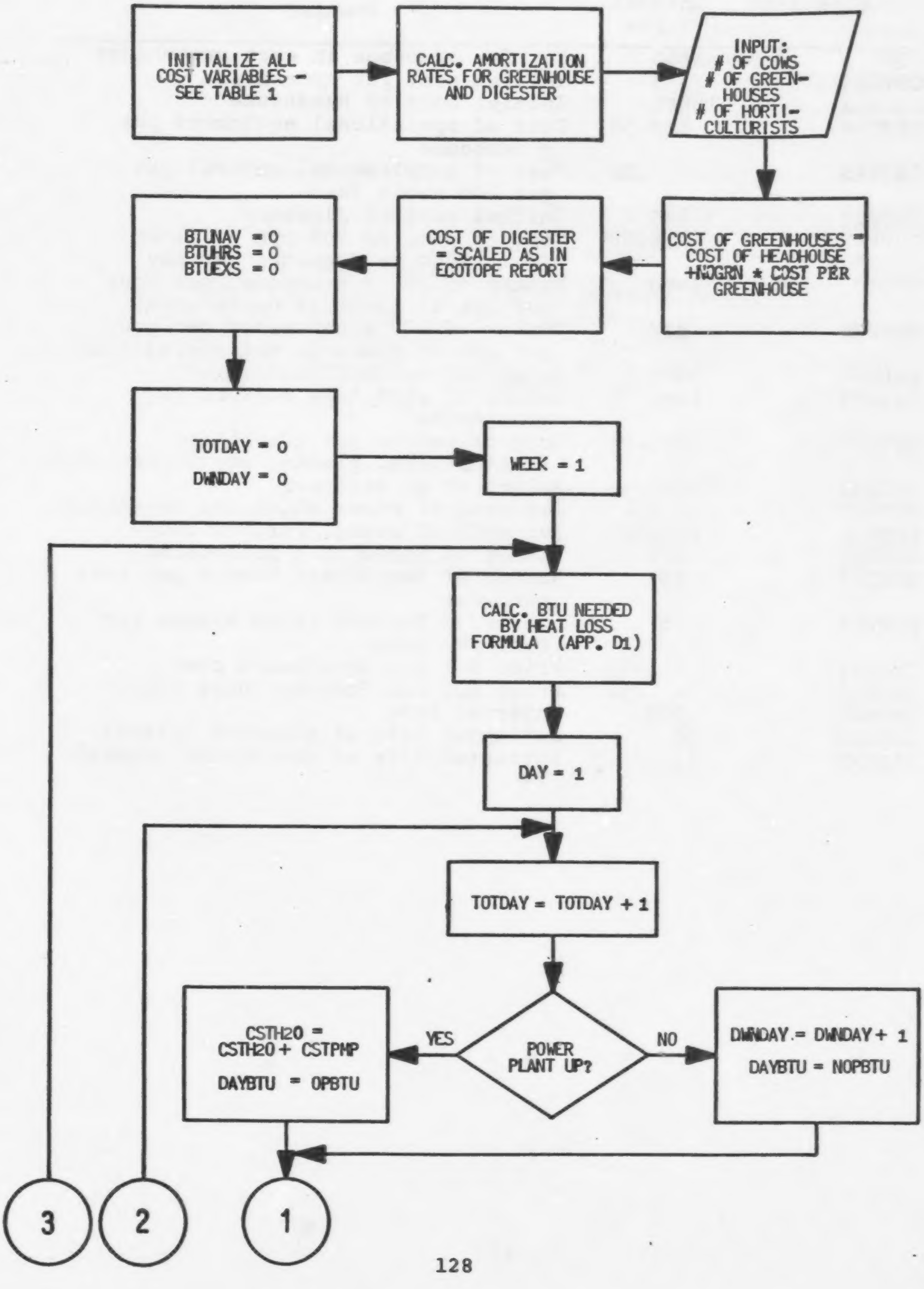
Note

* Engineer wages for running digester and methane gas plant have been included.

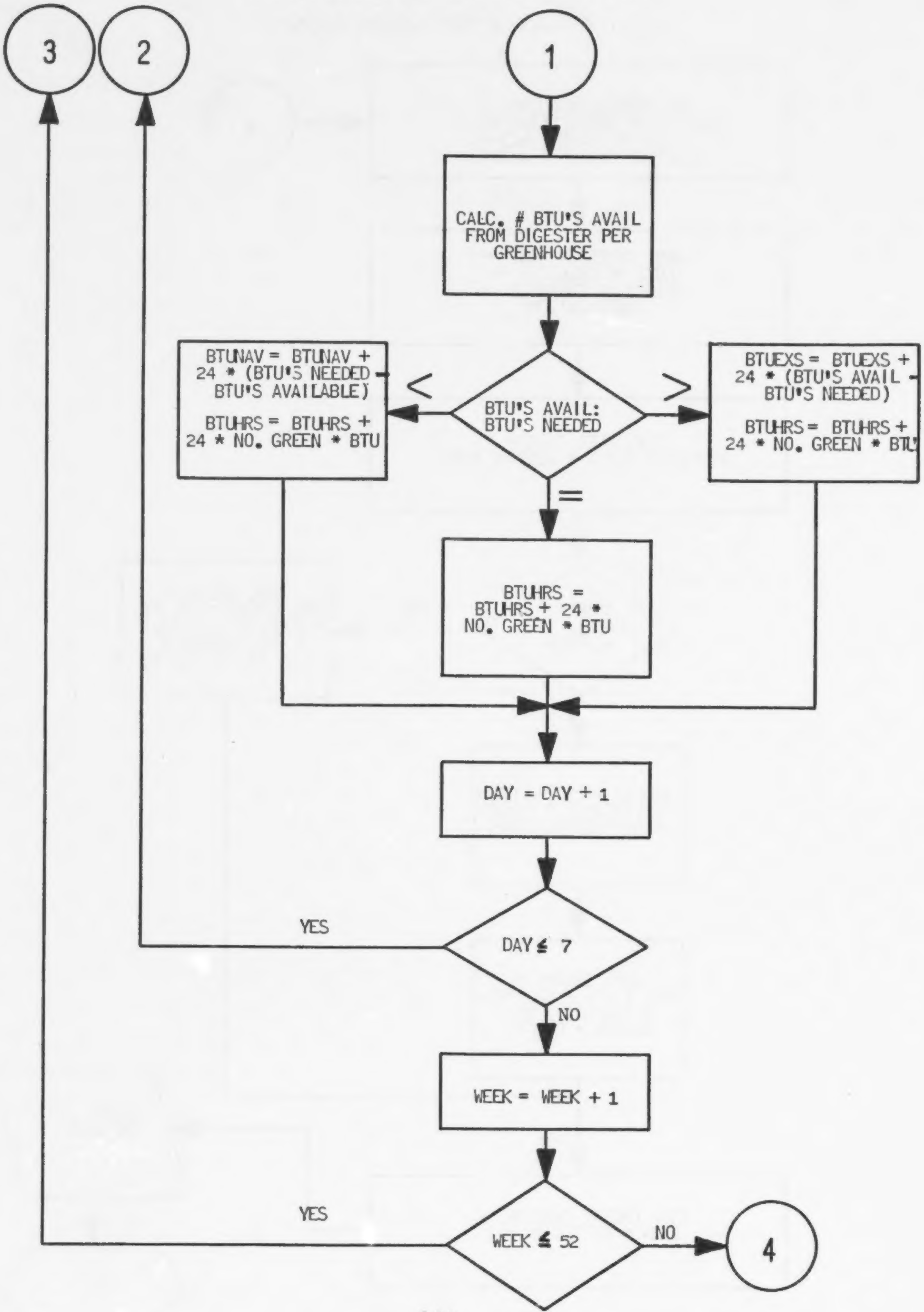
Table 2 - Description of Variables

Variable Name	Initial Value	Meaning
SQFT	1560	Sq. ft. of space in each greenhouse
CSTGRN	7355	Initial cost per greenhouse
CSTHDH	18000	Initial cost of headhouse
CSTOPN	837.50	Cost of operational equipment per greenhouse
CSTGAS	.22	Cost of supplemental natural gas per 100 cubic feet
CSTDIG	71040	Initial cost of digester
CSTPMP	2.08	Cost of pumping 200 gpm of water from plant to digester per day
OPBTU	1000	Number of BTU's generated per hour per cow if plant is operational
NOPBTU	625	Number of BTU's generated per hour per cow if plant is not operational
SALHOR	9600	Salary of one horticulturist
SALPRT	1650	Salary of part time workers per greenhouse
CSTEXT	1043.75	Cost of extras per greenhouse (fertilizers, plants, pesticides,etc)
SALENG	12000/yr	Salary of an engineer
PCTSWT	33.33%	Per cent of roses which are Sweetheart
PCTFOR	66.67%	Per cent of roses, Forever Yours
NUMROS	672	Number of roses in a greenhouse
NUMSWT	23	Number of Sweetheart blooms per rose per year
NUMFOR	36	Number of Forever Yours blooms per rose per year
PRCSWT	1.25	Price for one Sweetheart rose
PRCFOR	.52	Price for one Forever Yours rose
INTCAP	.095	Interest rate
LIFDIG	50	Estimated life of digester (years)
LIFGRN	25	Estimated life of greenhouse (years)

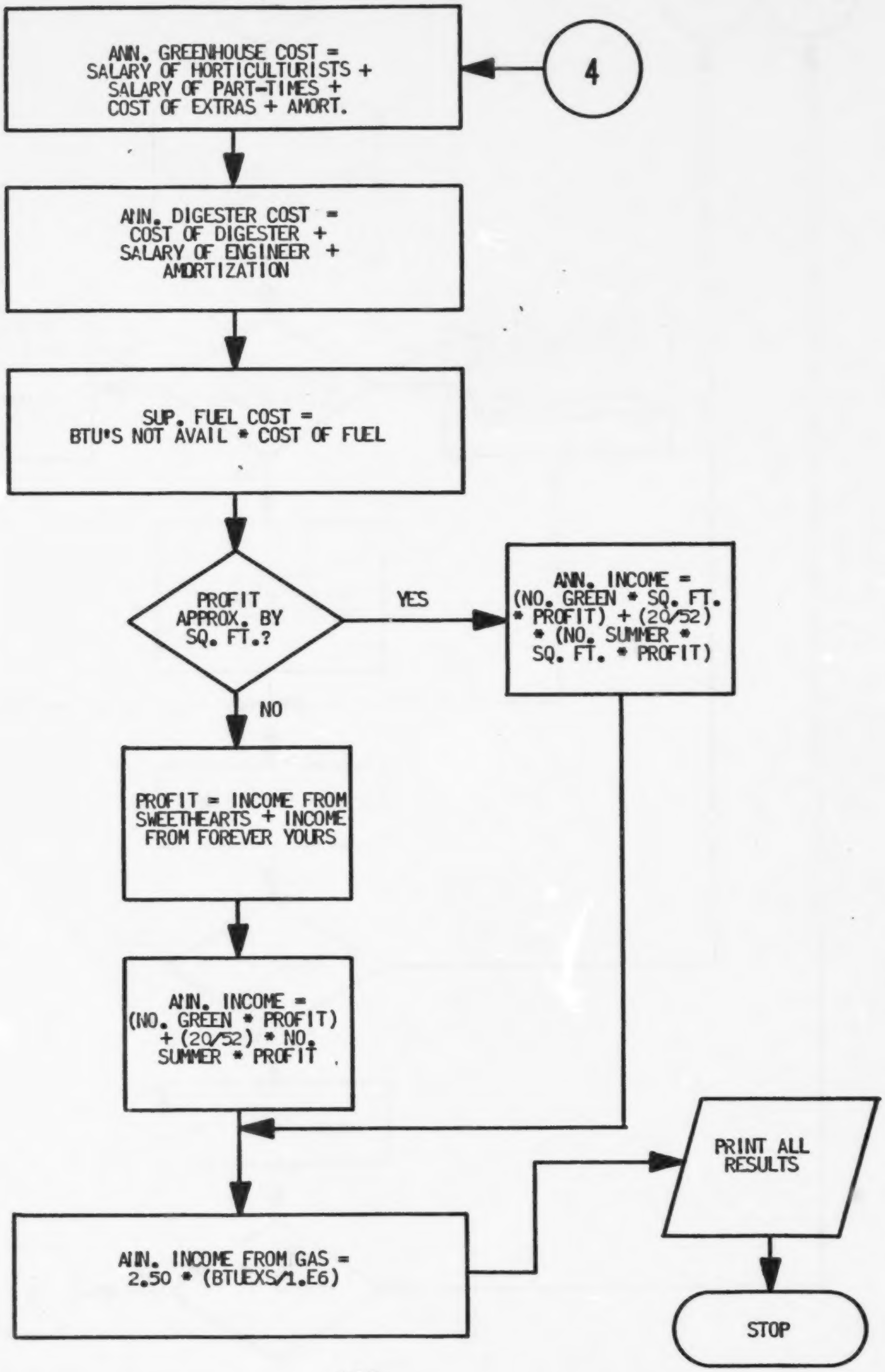
FLOW CHART OF THE MODEL


INITIALIZE ALL COST VARIABLES - SEE TABLE 1
CALC. AMORTIZATION RATES FOR GREENHOUSE AND DIGESTER
INPUT: # OF COWS # OF GREEN- HOUSES # OF HORTI- CULTURISTS
COST OF GREENHOUSES = COST OF HEADHOUSE +NOGRN * COST PER GREENHOUSE
COST OF DIGESTER = SCALED AS IN ECOTOPE REPORT
BTUNAV = 0 BTUHRS = 0 BTUEXS = 0
TOTDAY = 0
DWNDAY = 0
WEEK = 1
CALC. BTU NEEDED BY HEAT LOSS FORMULA (APP. D1)
DAY = 1
TOTDAY = TOTDAY + 1
POWER PLANT UP?
YES
NO
CSTH20 = CSTH20 + CSTPMP
DAYBTU = OPBTU
DWNDAY = DWNDAY + 1
DAYBTU = NOPBTU
3
2
1

FLOW CHART OF THE MODEL (CONT.)


3
2
1
CALC. # BTU'S AVAIL FROM DIGESTER PER GREENHOUSE
BTUNAV = BTUNAV + 24 * (BTU'S NEEDED - BTU'S AVAILABLE)
BTUHRS = BTUHRS + 24 * NO. GREEN * BTU
<
BTU'S AVAIL: BTU'S NEEDED
>
BTUEXS = BTUEXS + 24 * (BTU'S AVAIL - BTU'S NEEDED)
BTUHRS = BTUHRS + 24 * NO. GREEN * BTU
=
BTUHRS = BTUHRS + 24 * NO. GREEN * BTU
DAY = DAY + 1
YES
DAY ≤ 7
NO
WEEK = WEEK + 1
YES
WEEK ≤ 52
NO
4

FLOW CHART OF THE MODEL (CONT.)


4
ANN. GREENHOUSE COST = SALARY OF HORTICULTURISTS + SALARY OF PART-TIMES + COST OF EXTRAS + AMORT.
ANN. DIGESTER COST = COST OF DIGESTER + SALARY OF ENGINEER + AMORTIZATION
SUP. FUEL COST = BTU'S NOT AVAIL * COST OF FUEL
PROFIT APPROX. BY SQ. FT.?
YES
ANN. INCOME = (NO. GREEN * SQ. FT. * PROFIT) + (20/52) * (NO. SUMMER * SQ. FT. * PROFIT)
NO
PROFIT = INCOME FROM SWEETHEARTS + INCOME FROM FOREVER YOURS
ANN. INCOME = (NO. GREEN * PROFIT) + (20/52) * NO. SUMMER * PROFIT
ANN. INCOME FROM GAS = 2.50 * (BTUEXS/1.E6)
PRINT ALL RESULTS
STOP

```
C***************************************************************
C
C           GREENHOUSE MODELING PROGRAM
C
C***************************************************************
C THIS PROGRAM IS AN ECONOMIC MODEL OF A GREENHOUSE COMPLEX BEING
C HEATED BY BIOGAS PRODUCED BY A FARM WHICH HAS A DIGESTER WHICH
C IS PREHEATED BY WASTE HEAT FROM A POWER PLANT.
C
C  SOURCES ARE:
C     1.  WASTE HEAT UTILIZATION DEMONSTRATION GREENHOUSE DESIGN CONCEPT
C         PREPARED BY: D. R. PRICE, PHD
C     2.  PROCESS FEASIBILITY STUDY:  THE ANAEROBIC DIGESTION OF DAIRY COW
C         MANURE AT THE STATE REFORMATORY HONOR FARM MONROE, WASHINGTON
C         PREPARED BY:  ECOTOPE GROUP, RESEARCH CONSULTANTS
C                       PARAMETRIX INC., PROJECT ENGINEERS
C     3.  TED JOHNSON, MONTGOMERY ROSE  CO. (HADLEY, MA.)
C
C***************************************************************
      REAL INTCAP,MAXACR
      INTEGER Q (52),CODE,CODPRO,INDEX,DAY,WEEK
C AVERAGE WEEKLY TEMPERATURES AT GREENHOUSE SITE.
      INTEGER Q/-15,-15,-15,35,30,-15,-15,-15,40,48,35,42,54,40,40,65,
     1       38,43,50,52,52,66,58,66,70,77,70,66,75,70,77,66,68,79,59,
     2       63,60,52,54,62,46,40,40,-15,32,50,-15,-15,-15,-15,32/
C DATA FOR  SCALING  DIGESTER COST
C    SEE CHART ON PG. 87 OF REF 2 ABOVE
C     UNITS IS CATTLE UNITS
C     MULT IS MULTIPLIER
C     MTHCST IS MONTHLY COST
C
      REAL UNITS(5),MULT(5),MTHCST(5)
      DATA UNITS /350,525,700,875,1050/
      DATA MULT /1.0000,1.2754,1.5260,1.7488,1.9545/
      DATA MTHCST /400.76,511.14,611.56,700.85,783.29/
C***************************************************************
```

```
C
C VARIABLES FOR COST OF THE GREENHOUSE
C
C SQUARE FEET OF GROWING SPACE PER GREENHOUSE
C  GREENHOUSE SIZE IS 26 FT. BY 60 FT. OR 1560 SQ FT.
      SQFT = 1560
C COST PER GREENHOUSE (DESIGN # 4)
      CSTGRN = 7355.00
C COST FOR THE HEADHOUSE
      CSTHDH = 18000.00
C COST OF OPERATIONAL EQUIPMENT PER GREENHOUSE
      CSTOPN = 3350.00/4
C COST OF SUPPLEMENTAL NATURAL GAS PER 100 CUBIC FEET
      CSTGAS = .22
C**************************************************************
C
C VARIABLES FOR COST OF THE DIGESTER
C
C COST OF DIGESTER IN WASHINGTON (TOTAL PROJECT COST)
C    SEE  PG. 73-74 OF REF # 2 ABOVE
      CSTDIG = 71040.00
C**************************************************************
C
C VARIABLES FOR DAY-TO-DAY OPERATION
C
C COST OF PUMPING 200 GPM OF WATER FROM PLANT TO DIGESTER
C  PER DAY BASED ON N=30 AND .04/KWH
C
      CSTPMP = 2.08
C INITIAL COST OF PUMPING WATER TO PLANT IS ZERO
      CSTH2O = 0
C NO. OF BTU'S /HR/COW IF PLANT IS OPERATIONAL
      OPBTU = 1000
C NO. OF BTU'S /HR/COW IF PLANT IS NOT OPERATIONAL
      NOPBTU = 625
C**************************************************************
```

```
C
C VARIALES FOR ANNUAL OPERATION OF GREENHOUSE
C
C SALARY OF HORTICULTURIST
     SALHOR = 9600.00
C COST OF PART-TIME MAINT AND WORKERS PER GREENHOUSE
     SALPRT = 6600.00/4
C COST OF FERTILIZERS, PESTICIDES, VEHICLE, ELECTRICITY,
C  PLANTS,SEEDS,ETC. PER GREENHOUSE
     CSTEXT = 4175.00/4
C NUMBER OF GREENHOUSES A HORTICULTURIST CAN HANDLE
     GRNHRT = 4
C SALARY OF AN ENGINEER
     SALENG = 12000.00
C
C VARIABLES FOR ANNUAL INCOME FROM ROSES
C
C ALLOW USER TO INPUT PROFIT PER SQ. FT OR LET PROGRAM CALCULATE
C
     WRITE(6,700)
700  FORMAT('0DO YOU WISH TO INPUT PROFIT PER SQ. FT. OR HAVE',
    1 ' THE PROGRAM CALCULATE AN ESTIMATED PROFIT'/
    2 ' ENTER 1 FOR ESTIMATING NOW  OR 2 FOR PROGRAM CALCULATION')
705  READ(5,45) CODE
     IF (CODE .EQ. 1) GO TO 710
     IF (CODE .EQ. 2) GO TO 720
     WRITE (6,35)
     GO TO 705
C USER WISHES TO INPUT PROFIT PER SQ. FT.
710  WRITE (6,730)
730  FORMAT('0ENTER ESTIMATE OF PROFIT PER SQ. FT'/
    1 '   ENTER NUMBER WITHOUT DOLLAR SIGN AS DOLLARS AND CENTS')
     READ(5,45) PROFIT

C INDICATE SQ FT PROFIT ESTIMATE
     CODPRO = 1
C
```

```
      GO TO 740
C CALCULATE PROFIT  INTERNALLY
720   CODPRO = 0
C PER CENT OF ROSES WHICH ARE SWEETHEART
      PCTSWT = .3333333
C PER CENT OF ROSES WHICH ARE FOREVER YOURS
      PCTFOR = .6666667
C NUMBER OF ROSES PER GREENHOUSE SPACING AT 12 INCHES
C   (IF SPACING IS 11 INCHES THIS SHOULD BE 725)
      NUMROS = 672
C NUMBER OF FLOWERS PER PLANT PER YEAR (SWEETHEART)
      NUMSWT = 23
C NUMBER OF FLOWERS PER PLANT PER YEAR (FOREVER YOURS)
      NUMFOR = 36
C PRICE FOR SWEETHEART ROSES
      PRCSWT = 1.25
C PRICE FOR FOREVER YOURS ROSES
      PRCFOR = .52
C
C CALCULATE AMORTIZATION RATES
C INTEREST RATE FOR CAPITAL RECOVERY FACTOR
740   INTCAP = .095
C LIFE OF THE DIGESTER (YEARS)
      LIFDIG = 50
C LIFE OF THE GREENHOUSES (YEARS)
      LIFGRN = 25
C
C R1 IS FOR DIGESTER; R2 IS FOR GREENHOUSES
C
      R1 = INTCAP * (1 + INTCAP) ** LIFDIG/((1 +INTCAP)**LIFDIG -1)
      R2 = INTCAP * (1 + INTCAP) ** LIFGRN/((1 + INTCAP)**LIFGRN -1)
C******************************************************************
```

```
C
C FIGURE OUT HOW MANY GRENHOUSES YOU CAN OPERATE
C
C   ALLOW NO. OF COWS AND NO. OF GREENHOUSES TO VARY
C
      WRITE(6,10)
10    FORMAT('OHOW MANY COWS ARE THERE ON THE FARM (1 COW = 1250 '
     1'LB. OF CATTLE)')
      READ(5,45) NOCOWS
C NEED 200 COWS PER GREENHOUSE
      MAXGRN = NOCOWS / 200
      WRITE(6,15) MAXGRN
15    FORMAT('OYOU MAY SUPPORT',I5,' GREENHOUSES')
      MAXACR = (MAXGRN * SQFT)/43560.
      WRITE(6,20) MAXACR
20    FORMAT(' THIS IS EQUIVALENT TO ',G,'  ACRES')
C
100   WRITE(6,25)
25    FORMAT('OWOULD YOU LIKE TO ENTER THE DESIRED AREA IN ACRES (1)'
     1,' OR GREENHOUSES (2)'/T10,'(ENTER 1 OR 2)')
      READ(5,30) CODE
30    FORMAT(I1)
      IF (CODE .EQ. 1) GO TO 110
      IF (CODE .EQ. 2) GO TO 120
C CODE ENTERED IN ERROR
      WRITE(6,35)
35    FORMAT('OCODE MUST BE ENTERED AS A 1 OR 2'/
     1,'PLEASE REENTER')
      GO TO 100
C PROCESS AREA IN ACRES
110   WRITE(6,40)
40    FORMAT('OHOW MANY ACRES DO YOU WISH TO CULTIVATE')
      READ(5,45) ACRREG
45    FORMAT(G)
      NOGRN = (ACRREG*43560)/SQFT +.5
      GO TO 130
```

```
C PROCESS AREA IN NUMBER OF GREENHOUSES
120   WRITE(6,50)
50    FORMAT('OHOW MANY GREENHOUSES WOULD YOU LIKE')
      READ(5,45) NOGRN
130   WRITE(6,55) NOGRN
55    FORMAT('OYOU HAVE',I5,' GREENHOUSES')
C SEE IF MORE THAN WE CAN SUPPORT
      IF(NOGRN .GT. MAXGRN) WRITE(6,60) MAXGRN
60    FORMAT('ONOTE: YOUR SYSTEM CAN ONLY SUPPORT ',I5,
     1 ' HEATED GREENHOUSES WITHOUT SUPPLEMENTAL HEAT')
C CHECK FOR SUMMER GREENHOUSES - NO EXTRA HEAT REQUIRED
140   WRITE(6,65)
65    FORMAT('OWOULD YOU LIKE ANY SUMMER GREENHOUSES (THESE ARE '
     1 ,'HOUSES WHICH ONLY OPERATE IN THE SUMMER, WHICH IN TURN, '
     2 ,' REQUIRE NO EXTRA HEAT)'/' ENTER 1 FOR YES, 2 FOR NO')
      NOSUM = 0
      READ (5,30) CODE
      IF (CODE .EQ. 1) GO TO 150
      IF (CODE .EQ. 2) GO TO 170
      WRITE(6,35)
      GO TO 140
C PROCESS SUMMER GREENHOUSES
150   WRITE(6,25)
      READ(5,30) CODE
      IF (CODE .EQ. 1) GO TO 160
      IF (CODE  EQ. 2) GO TO 180
C CODE ENTERED IN ERROR
      WRITE(6,35)
      GO TO 150
C PROCESS SUMMER GREENHOUSES IN ACRES
160      WRITE(6,40)
         READ(5,45) ACRSUM
         NOSUM = (ACRSUM * 43560)/ SQFT + .5
         GO TO 170
C PROCESS SUMMER GREENHOUSES IN NUMBER OF GREENHOUSES
180   WRITE(6,70)
70    FORMAT('OHOW MANY SUMMER GREENHOUSES WOULD YOU LIKE')
      READ(5,45) NOSUM
170   WRITE(6,75) NOSUM
75    FORMAT('0 YOU HAVE',I5,' SUMMER GREENHOUSES')
```

```
C
C INPUT THE NUMBER OF HORTICULTURISTS
      WRITE(6,80) GRNHRT
80    FORMAT('OHOW MANY HORTICULTURISTS  DO YOU WANT FOR THE YEAR ',
     1'ROUND GREENHOUSES (1 PER',I5,' GREENHOUSES IS RECCOMMENDED')
      READ(5,45) REGHOR
C CHECK IF SUMMER GREENHOUSES
      IF (NOSUM .EQ. 0) GO TO 200
C HAVE SUMMER GREENHOUSES
      WRITE(6,85)
85    FORMAT('OHOW MANY HORTICULTURISTS DO YOU WANT FOR THE'
     1,' SUMMER GREENHOUSE')
      READ(5,45) SUMHOR
      GO TO 210
C  NO SUMMER GREENHOUSES
200   SUMHOR = 0
210   WRITE(6,90) REGHOR,SUMHOR
90    FORMAT('OYOU HAVE ',I3,' HORTICULTURISTS FOR THE ',
     1'YEAR ROUND GREENHOUSES AND 'I3,' HORTICULTURISTS FOR THE ',
     2'SUMMER GREENHOUSES')
C******************************************************************
C
C ALL DATA ENTERED - NOW START THE  SIMULATION
C
C  INITAILIZE RANDOM NUMBERS FOR POWER PLANT UP CALCULATIONS
C
      CALL RANDOM(1,IY,RAND)
      IX=IY
C
C INITIAL COST OF ALL GREENHOUSES
C
      INTGRN = CSTHDH + (NOGRN + NOSUM) * (CSTGRN + CSTOPN)
C
C
C INITIAL COST OF DIGESTER - REFER TO PG.85-89 OF REF. # 2 ABOVE
C
C  CONVERT COW UNITS TO DIGESTER CATTLE UNITS
C    NOTE: ONE DIGESTER COW UNIT IS 1000 LB OF CATTLE
C            ORIGINAL COW ASSUMED AT 1250 LBS
```

```
C
      CATUNT = (1250./1000) * NOCOWS
      SAVUNT = CATUNT
C CALCULATE HOW MANY SEPARATE UNITS ARE NEEDED
C
C FIRST ASSUME ONE DIGESTER
C
      NODIG = 1
C
215   DO 220 INDEX = 1,5
         IF (CATUNT .LE. UNITS(INDEX)) GO TO 230
220   CONTINUE
C NEED MORE DIGESTERS - TRY ONE MORE
C
      NODIG = NODIG + 1
C MODIFY CATTLE UNITS TO REFLECT NEW DIGESTER
      CATUNT = SAVUNT / NODIG
      GO TO 215
C
C INDEX POINTS TO SIZE OF THE DIGESTER
C CALCULATE INITIAL DIGESTER COST
C
230   INTDIG = NODIG * (MULT(INDEX)*CSTDIG)
C****************************************************************
C
C SIMULATE DAY-TO-DAY OPERATION
C
C NOTE: THESE COMPUTATIONS ARE FOR ONE GREENHOUSE
C
C BTUNAV - BTU'S NEEDED IN EXCESS OF DIGESTER OUTPUT (FOR 1  GREENHOUSE)
C BTUHRS - # OF HOURS OF PUMPING GAS FROM DIGESTER TO 1 GREENHOUSE
C         (1 HR. IS PUMPING 200000 BTU TO 1 GREENHOUSE)
C BTUEXS - EXCESS BTU'S PRODUCED BY THE DIGESTER
C
C SET COUNTERS TO ZERO
      BTUNAV = 0
      BTUHRS = 0
      BTUEXS = 0
C
```

```
C TOTDAY - TOTAL NUMBER OF DAYS
    TOTDAY = 0
C DWNDAY - TOTAL NUMBER OF DAYS PLANT IS DOWN
    DWNDAY = 0
C PROCESS FOR ALL WEEKS IN A YEAR
    DO 310 WEEK = 1 , 52
C
C CALCULATE HEAT LOSSES
      TMP1 = 57.5 - Q(WEEK)
C CHECK IF NO BTU'S REQUIRED
      IF (TMP1 .LE. 0) GO TO 250
      TMP2 = 30
      IF (Q(WEEK) .LE. TMP2) GOTO 240
      TMP2 = Q(WEEK)
C CALC HEAT LOSS BY HEAT LOSS FORMULA IN APPENDIX
240   BTU = 80*(57.5-TMP2)+TMP1*(212.4+457+53+219)
      GO TO 260
C NO HEAT REQUIRED
250   BTU = 0
260   CONTINUE
C
C GO THROUGH SEVEN DAYS PER WEEK
C
      DO 310 DAY = 1 , 7
C INCREMENT DAY COUNTER

        TOTDAY = TOTDAY + 1
C IS PLANT UP TODAY
        CALL RANDOM(IX,IY,RAND)
        IX=IY
        IF (RAND*100 .LE. 90) GO TO 270
C NO -- PLANT IS DOWN - BOOST DOWN DAYS
        DWNDAY = DWNDAY + 1
C AND AMOUNT OF BTU'S /COW PRODUCED IS REDUCED
        DAYBTU = NOPBTU
        GO TO 280
C PLANT IS UP -- PUMP WATER FROM PLANT TO DIGESTER
270     CSTH2O = CSTH2O + CSTPMP
        DAYBTU = OPBTU
```

```
C CALC NUMBER OF BTU'S AVAILABLE FOR GREENHOUSE
280           TEMP = NOCOWS * DAYBTU /NOGRN
              IF (BTU .NE. TEMP) GO TO 290
C BTU NEEDED AND AVAILABLE ARE THE SAME
C    MORE GAS TO THE GREENHOUSES
              BTUHRS = BTUHRS + 24 * BTU * NOGRN
              GO TO 310
C BTU NEEDED AND AVAIL ARE NOT THE SAME
290           IF (BTU .LT. TEMP) GO TO 300
C # BTU'S REQUIRED ARE MORE THAN AVAILABLE
C   PUMP AS MUCH AS POSSIBLE TO GREENHOUSES
                 BTUNAV = BTUNAV + 24 * ((BTU*NOGRN)-(NOCOWS*DAYBTU))
                 BTUHRS = BTUHRS + 24 *(NOGRN *TEMP)
                 GO TO 310
C # BTU'S REQUIRED LES THAN THE AVAILABLE -
C   CALC EXCESS GAS
300              BTUEXS = BTUEXS + 24 *((NOCOWS*DAYBTU)-(BTU*NOGRN))
                 BTUHRS = BTUHRS + 24 * NOGRN * BTU
310   CONTINUE
C
C ANNUAL COST OF GREENHOUSES
C
      ANGRN = SALHOR * REGHOR + SALHOR * (20./52) +
     1          NOGRN * (SALPRT + CSTEXT) +
     2          NOSUM*(SALPRT+CSTEXT)*(20./52) +
     3          R2 * INTGRN
C
C ANNUAL COST OF DIGESTER
C
      ANDIG  = NODIG * (12 *MTHCST(INDEX)) + SALENG + R1 * INTDIG
C
C COST OF SUPPLEMENTAL FUEL
C
      ANSUP = BTUNAV / 1000 * CSTGAS / 100
C
C ANNUAL INCOME FROM ROSES
C
C IS ESTIMATE PER SQ FT OR INTERNALLY CALCULATED
```

```
C
        IF (CODPRO .EQ. 1) GO TO 330
C
        ANINC = NOGRN *(PCTSWT * NUMROS * NUMSWT * PRCSWT  +
       1                    PCTFOR * NUMROS * NUMFOR * PRCFOR)
C
C ANNUAL INCOME FROM SUMMER GREENHOUSES
C
        ANSUM = NOSUM *(PCTSWT*NUMROS*(20./52)*NUMSWT*PRCSWT +
       1                    PCTFOR*NUMROS*(20./52)*NUMFOR*PRCFOR)
        GO TO 340
C CALCULATE PROFIT BY SQ. FT.
C
330     ANINC = NOGRN * SQFT * PROFIT
        ANSUM = NOSUM * SQFT * PROFIT * (20./52)
C
C CALCULATE INCOME FROM SALE OF EXCESS GAS
C
C  AT 2.50 PER 10 TO THE SIXTH BTUS
C
        ANGAS = 2.50 * (BTUEXS / 1.E6)
C
C
C PRINT THE RESULTS
C
C   COSTS FIRST
C
340     WRITE(6,500) INTGRN
500     FORMAT('0THE INITIAL COST FOR THE GREENHOUSE COMPLEX IS $',I8)
        WRITE(6,510) NODIG,INTDIG
510     FORMAT('0THE INITIAL COST FOR THE DIGESTER COMPLEX OF ',
       1 I4,' DIGESTERS IS $',I8)
        WRITE(6,520) ANGRN
520     FORMAT('0THE ANNUAL RUNNING COSTS FOR THE GREENHOUSES IS $',I8)
        WRITE(6,530) ANDIG
530     FORMAT('0THE ANNUAL RUNNING COSTS FOR THE DIGESTER IS $',I8)
        WRITE(6,540) CSTH2O
540     FORMAT('0THE ANNUAL COST FOR PUMPING WATER FROM THE PLANT TO ',
       1 'THE DIGESTER IS $',I8)
```

```
          WRITE(6,550) ANSUP
    550   FORMAT('OTHE ANNUAL COST OF SUPPLEMENTAL FUEL IS $',I8)
          TOT = ANGRN + ANDIG + CSTH2O + ANSUP
          WRITE(6,560) TOT
    560   FORMAT('OTHE TOTAL ANNUAL COST OF OPERATION IS $',I8)
    C
    C NOW COMPUTE THE INCOMES
    C
          TOT = ANINC + ANSUM
          WRITE(6,570) TOT
    570   FORMAT('0 THE ANNUAL INCOME FROM ROSES IS $',I8)
          WRITE(6,582) ANGAS
    582   FORMAT('OTHE ANNUAL INCOME FROM BIOGAS IS $',I8)
          WRITE(6,580) BTUHRS
    580   FORMAT('OTHE NUMBER OF BTU''S WHICH WERE PUMPED FROM THE',
         1' DIGESTER TO ALL THE GREENHOUSES IS :',G)
          WRITE(6,590) BTUNAV
    590   FORMAT('OTHE NUMBER OF BTU''S NEEDED THAT WERE NOT ',
         1 'AVAILABLE WERE',G)
          WRITE(6,600) BTUEXS
    600   FORMAT('OTHE NUMBER OF EXCESS BTU''S PRODUCED ',
         1 'BY THE DIGESTER WERE:' ,G)
          WRITE(6,610) DWNDAY,TOTDAY
    610   FORMAT('OTHE PLANT WAS NOT OPERATIONAL ',I5,' OF THE TOTAL',I5,
         1' DAYS')
    C
          PERCNT = 100. * (DWNDAY/TOTDAY)
    C
          WRITE(6,620) PERCNT
    620   FORMAT('0',T10,'THIS AMOUNTS TO ',I5,' PERCENT OF THE TIME')
          WRITE(6,630)
    630   FORMAT('OINCOME NOT INCLUDED IN THE SIMULATION INCLUDES THE'
         1 ' SALE OF EXCESS METHANE AND THE DRIED SLUDGE AS FERTILIZER')
          CALL EXIT
          END
```

```
      SUBROUTINE RANDOM (IX,IY,YFL)
      IY=IX*65539
      IF(IY)5,6,6
    5 IY=IY+2147483647+1
    6 YFL=IY
      YFL=YFL*.4656613E-9
      RETURN
      END
```

ANNEX TO APPENDIX D

HEAT LOSS CALCULATIONS FOR GREENHOUSE NO. 4

by Joe Kent

General Heat Loss Equation

$$Q = UA\,\Delta T$$

$$\Delta T = To - Ti$$

$$U = \frac{1}{\underset{n}{R}_{Tn}}$$

$$R_T = \underset{i=1}{\Sigma} R_i$$

Floor Losses

Air R= 0.62

3" porous conc R= 3.33

6" of 5/8" Blue Stone R=0.87

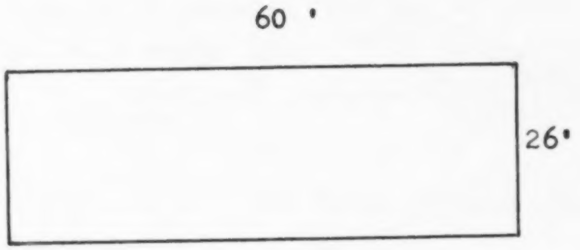
R =1.09 vinyl liner

2" styrofoam ⟶ R =12.5

polyethylene ⟶ R =1.09

earth

$\Sigma R = 19.50$



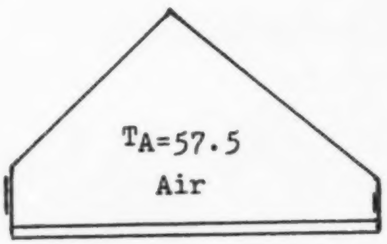
Minimum temp. for earth = 30°F

$Q = UA\,(T_A - T_G)$ Min. value

$Q_F = \frac{1}{19.5}\,(26)(60)(57.5-30)$

$Q_F = 80 \quad 57.5 - Q(W)$ BTU/hr

Q(W) For earth not less than 30°F



T_G = 30°F for greater

Ground Temp.

Minimum = 30°F

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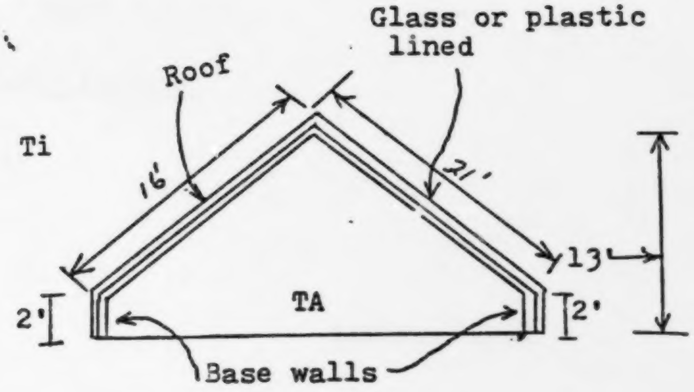
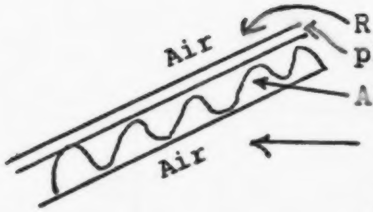
Losses for Greenhouse

Insulated roof


Glass or plastic lined
Roof
Ti
16'
21'
13'
2'
TA
2'
Base walls



R = 0.17
plywood R =0.93
Air space R =2.80
R = 0.62

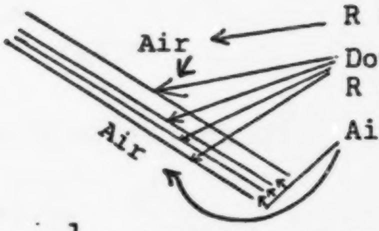
$\Sigma R = 4.52$

A=(16)(60)= 960 sq.ft.

$$\text{Heat loss } Q_R = UA\,(T_i - T_A) = \frac{1}{4.52}\,(960)\,(Ti - T_A)$$
$$= \underline{212.4}\,(Ti - T_A) \quad \leftarrow Q\text{ roof}$$

BTU/hr

Glass or Plastic Lined



R = 0.17
Double plastic
R = 2.0
Air R = 0.62

$\Sigma R = 2.79$

Area=(21)(60)+15
=1275 sq.ft.

$$\text{Heat loss} = \frac{1}{2.79}\,(1275)(Ti-T_A) = \underline{457\ (Ti-T_A)} \leftarrow \text{Roof liner}$$

BTU/hr

Base Wall

Same R as roof R = 4.52 Area = 2(60)(2) = 240 sq. ft.

$$Q_{BW} = \frac{1}{4.52}\,(240)(Ti - T_A) = 53\,(Ti - T_A)$$

Infiltration losses Specific Heat Air = .240 BTU/lb.°F

Ambient air temperature = 50°F

$$p v_s = RT$$

$$v_s = \frac{RT}{p} \qquad \frac{1}{\gamma} = \frac{RT}{P} = \frac{(53.3)(460 + 50)}{(14.7)(144)} = 0.078 \text{ lb/cf}$$

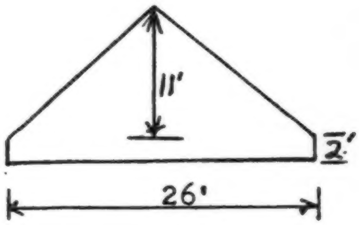
Infiltration $\sim$/change/hour

$$\text{Volume} = 26(2)(60) + \frac{26(11)}{2}(60) = 11{,}700 \text{ cf}$$

Heat lost to infiltration

$$= (0.24)(11{,}700)(.078)(T_i - T_A)$$

$$= 219(T_i - T_A) \text{ BTU/hr}$$



SUMMARY OF LOSSES

Floor $Q_F = 80\ [57.5 - Q(W)]$ $\quad Q(W) \geq 30$

Roof $Q_R = 212.4(T_i - T_A)$

Glass $Q_G = 457\ (T_i - T_A)$

Base Wall $Q_{BW} = 53\ (T_i - T_A)$

Infiltration $Q_I = 219\ (T_i - T_A)$

Q Total $= 80\ [57.5 - Q(W)] + (T_i - T_A)(212.4 + 457 + 53 + 219)$